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Neurophysiological correlates of templates-for-rejection and modulatory effects of emotion

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Neurophysiological correlates of templates-for-rejection and modulatory effects of emotion

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By

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A thesis submitted in partial fulfilment of the requirements for the degree of PhD

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2019

Declaration of Originality

I, Janine Claire Anim, hereby declare that this work was carried out in accordance with the Regulations of the University of Roehampton. I declare that this submission is my own work, and to the best of my knowledge does not represent the work of others, published or unpublished, except where duly acknowledged in the text. No part of this thesis has been submitted for a higher degree at another university or institution.

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Date: Monday 7th October 2019

Abstract

Previous visual search studies have revealed that target identification can be facilitated by foreknowledge of a salient distractor's feature(s). The term 'templates-for-rejection' (coined by Woodman & Luck, 2007) has been used to refer to this effect and mechanisms of active suppression are proposed to be involved (e.g.,Gaspelin & Luck, 2019; Sawaki & Luck, 2010). To date, there has been an absence of research into the possible underlying neural mechanisms of templates-for-rejection for stimuli possessing socio-motivational relevance. The first three experiments of this thesis therefore used facial expression stimuli to investigate this issue. Experiment one (Chapter 2) presented face pairs bilaterally and participants reported the sex of the non-neutral face (neutral template-for-rejection block), or the non-angry face (angry template-for-rejection block). For comparison, participants also reported the sex of the neutral, or angry face (neutral vs. angry template-for-selection blocks). The template-matching face appeared beside either a happy, sad, surprised, or disgusted face. Electroencephalography (EEG) was recorded with event-related-potentials (ERPs) time-locked to the onset of the faces. Accuracy and response times were also measured. An ERP component previously considered to reflect active suppression was observed in response to neutral, but not angry, templates-for-rejection. However, what appeared to be active suppression of neutral templates could have been attentional capture by the more emotionally salient face on the opposite side. Experiments two (neutral templates) and three (angry templates) (Chapters 3 and 4) used the same faces, but with one face appearing on the midline and the other to the left or right of fixation, in order to isolate the ERP response to the lateral stimulus. For the neutral templates-for-rejection only, active suppression was revealed, consistent with previous studies using non-motivationally relevant stimuli. This effect appeared to arise at a relatively late stage of processing, suggesting that distractor representations may have been suppressed within visual working memory (VWM) to prevent ongoing engagement with task-irrelevant stimuli. In line with the findings from Experiment one, there was no evidence of active suppression of angry templates. This may indicate the resistance of angry facial expressions to suppression, but it is also the case that angry faces may have been harder than neutral faces to perceptually discriminate from paired emotional expressions; thus, an interpretation in terms of task difficulty for the absence of active suppression of angry face templates-for-rejection cannot be ruled out. Experiment four (Chapter 5) was therefore carried out in part to explore

the role of task difficulty on ERP indices of active suppression using non-motivationally relevant colour singletons. Attentional control was better under easy (crowded array), compared with hard (sparse array) task conditions. For crowded displays only, active suppression of non-targets occurred during late attention processing which was earlier than in experiment two. It is possible therefore that an apparent lack of active suppression for angry templates-for-rejection in experiments one and three may have been due to task difficulty as well as the aversive motivational significance of the stimuli. In contrast to experiment two (neutral template findings), there was no evidence that continued engagement with the non-motivationally relevant stimuli was actively terminated within the late VWM processing stage. Notably, the ERP profile of response in Experiment four corresponded to a template for rejection impairment with respect to speed and accuracy of target identification. Experiment five (Chapter 6) sought to explore the role of increased perceptual difficulty under equivalent high cognitive demands as experiment four, in order to investigate the conditions necessary for a behavioural templates-for-rejection benefit to emerge. To conclude, this thesis demonstrates that active suppression of template distractors may be influenced by the motivational relevance and threat value of stimuli, and also cognitive and perceptual task demands. The absence of a clear behavioural template-for-rejection benefit across experiments is explained in terms of delayed active suppression due to high cognitive demands associated with the requirements to switch between template features.

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Chapter 1: General Introduction

1.1 Introduction

The question of how humans navigate cluttered and multidimensional visual environments has been a topic of much investigation over the past decades. Due to capacity limitations, humans cannot process all available inputs in the visual environment; therefore, visual attention is required to select and process only the most relevant inputs (Wolfe & Horowitz, 2004). The factors that influence which inputs will be processed, to what extent, and how are still topics that generate a lot of interest and empirical investigation. Automatic prioritisation of salient stimuli, termed 'bottom-up processing' can be crudely activated by stimulus colour, social relevance, or visual contrast against surrounding inputs. However, contributions from top-down mechanisms which selectively process visual inputs based on current goals (see: Theeuwes, 1991, 2010a, 2010b; Theeuwes & Burger, 1998) can also influence processing. Theories of attention commonly stipulate that interactions between bottom-up (automatic) and top-down (controlled) attention underpin the process of selecting task-relevant stimuli (e.g., Bundesen, 1990; Bundeson et al., 2005; Desimone & Duncan, 1995; Treisman, 1988; Wolfe, 1994).

The Selection History Hypothesis states that both target acuity and distractor suppression can be facilitated when a specific feature or location can be reliably predicted (see Maljkovic & Nakayama, 1994; Chun & Jiang, 1998; Wang & Theeuwes, 2018a; Theeuwes, 2018). Similarly, the Contingent Voluntary Orienting Hypothesis outlines that salience-driven attentional capture can be prevented by means of processing being primarily guided by memory, knowledge or expectations (e.g., Folk & Anderson, 2010; Bacon & Egeth, 1994; Becker, Folk, & Remington, 2010; Folk, Remington, and Wright, 1994). The influence of selection history (previous experience) in facilitating the processing of a specific feature or location also forms the basic assumption of the more prominent neural theories of visual attention (e.g.,Bundesen, 1990, Bundesen et al, 2005; Desimone & Duncan, 1995).

Desimone and Duncan's (1995) Biased Competition Theory (BCT) states that objects in the visual field compete for representation in visual cortex. According to BCT task relevant features (also termed 'templates') can be learned and maintained in working memory (WM) on spatially representative salience maps. By these means attention can be pulled toward template matching signals during early

perceptual processing stages; through augmentation of integrated neural mechanisms throughout the brain this process can be fine-tuned and enhanced with experience of specific search features (for similar accounts and empirical support see: Beck & Kastner., 2009; Chalazzi, Duncan, Miller, & Desimone.,1998; Kastner, De Simone, Konen, Szczepanski, Weiner, Schneider., 2007; Kastner, De Weerd, Desimone, & Ungerleider, 1998; Schluppeck, Curtis, Glimcher, & Heeger., 2006; Silver & Kastner, 2009).

Similar to BCT is Bundesen's Neural Theory of Visual Attention (NTVA) (see Bundesen, 1990; Bundesen et al., 2005). The theory states that target representations maintained in visual working memory (VWM) during search interact with attention networks in inferotemporal cortex. Through dynamic remapping of cortical cells with feature sensitive receptive fields, high attentional weights can be set to facilitate processing of visual inputs with target features. Both neural theories (BCT and NTVA) highlight the importance of previous experience with template features and the integration of features held in VWM with neural circuitry involved in perception and attention. Both BCT and NTVA provide very good accounts of the neural circuitry that may underpin findings of improved visual search capabilities when individuals have experience with a searched for feature (e.g.,Awh, Belopolsky & Theeuwes, 2012; Chun & Jiang, 1998; Umemoto, Scolari, Vogel, & Awh, 2010; Logan, 2002).

In addition to theories that account for the cognitive underpinnings of target selection, more recent hypothesis testing has surrounded the neural dynamics that support distractor suppression; in particular, how we terminate attentional selection of, or prevent attentional capture by salient but task irrelevant stimulus inputs. Through a series of experiments Lavie, Hirst, de Fockert, & Viding (2004) found evidence that *high perceptual load* (e.g.,large relevant set size) enhanced ability to suppress activation of neural networks involved in distractor evoked attentional capture; whereas, *high working memory load* (e.g.,dual task set) reduced ability to suppress activation of neural networks involved in distractor evoked attentional capture. Two selective attention mechanisms were subsequently proposed by Lavie et al. (2004): 1) A perceptual selection mechanism that functions to reduce perception of distractors under conditions of high perceptual load, and which exhausts perceptual capacity for processing irrelevant stimuli. 2) A cognitive control mechanism that lessens interference by

perceived distractors as long as cognitive control function is available (low cognitive load) to maintain processing priorities. Lavie et al's. (2004) Load Theory suggests that early attention processing can be controlled to avoid distractors when adequate resources are available for top-down control mechanisms to do so.

In summary, a number of similar theories highlight a role for VWM templates in enhancing individuals capabilities when searching for a known target. With respect to avoiding visual inputs that are irrelevant to task goals, Load Theory explains that both the availability of processing resources and the perceptual demands of a given task are crucial in determining when attention can be controlled to avoid distracting inputs. Neural theories suggest that interactions between perceptual attention and VWM templates can facilitate individuals ability to search for relevant inputs, but these theories do not extend to the neural circuitry that may underlie how individuals suppress attentional selection of irrelevant distractor inputs. The primary aim of this thesis is to contribute to understanding the neural dynamics that underlie individuals ability to use known distractor features to avoid or terminate inappropriate distractor selection.

1.1.1: *Templates-for-rejection*

In the past decade, new research into controlled distractor suppression has emerged with a focus on template-guided suppression. Woodman and Luck (2007) carried out a study that aimed to test some of the assumptions of Biased Competition Theory (BCT); in particular, that object features held in VWM receive attentional resource prioritisation when they appear in a scene. Woodman and Luck (2007) tasked participants to remember a coloured square, complete a target search task, then a memory test to recall the colour of the square. The search task comprised an array of differently coloured squares. A single target was defined by a gap present in the upper or lower section of the square, whereas distractors were defined by a gap present in the left or right section of the square. Crucially, the memory-matching coloured square either appeared as a distractor (50% trials), or did not

appear at all (neither target nor distractor) (50% trials). Consistent with BCT, Woodman and Luck (2007) predicted impaired and therefore slower target identification when the memory-matching colour appeared as a distractor, compared to when it did not. In fact, the opposite occurred. Faster target identification was associated with the presence, rather than the absence of the memory-matching distractor. An extension to BCT was proposed by the authors to explain the unexpected findings; while object features held in working memory may indeed receive attentional resource prioritisation, attentional resources may in fact be utilised to guide attention away from, as well as toward those object features. Woodman and Luck (2007) coined the term 'templates-for-rejection' (t-f-r) to describe that items held in visual working memory (VWM) may be utilised for guided suppression as well as selection.

Arita, Carlisle, and Woodman (2012) employed a similar search task to Woodman and Luck (2007). A single target square appeared amongst a number of distractor squares. Variations of their paradigm presented four, eight, or twelve squares on the circular circumference of a central fixation cross. The squares were split so that those on the left appeared in a different colour to those on the right and participants searched for a single target square (defined by the position of a gap missing from its top or bottom side), amongst distractor squares (defined by left, or right sided gap position). Negative, positive and neutral cue blocks corresponded to the relevance of a colour cue that respectively indicated the salient feature of the target, distractor, or none of the search stimuli, at the start of each trial. Targets were identified faster on negative, versus neutral cue blocks for eight and twelve item displays; though on the four item display the target was identified at equal rapidity on negative and neutral cue blocks. Irrespective of the number of display items, positive cue blocks were associated with the fastest target identification. The finding that a negative cue benefit emerged during eight and twelve item search, but not four item search may suggest that, similar to the predictions of Load theory (Lavie et al., 2004), perceptual difficulty drives the utility of VWM maintained features as t-f-r. However, an alternative explanation for the findings may be that because the stimuli used for the Arita et al. (2012) study appeared in two different colors, grouped by visual hemifield, feature information was actually converted into spatial information; for example, when cued to avoid blue, the hemifield containing blue could have been quickly identified and then oriented away from so that the

opposite side of the screen could be searched. Support for this potential strategy of spatially recoding feature information is provided by Munneke, van der Stigchel, and Theeuwes (2008) who observed a reliable benefit for cuing distractor location compared to an uninformative cue. In another study (Moher & Egeth, 2012) target identification was faster when both the colour and location of a salient distractor were pre-cued. This t-f-r benefit to response speed disappeared when the location cue was absent and only the colour of the search distractor was pre-cued. Moher and Egeth (2012) proposed a "search and destroy" mechanism that works by actively seeking out cue matching distractors to facilitate later avoidance. Because Arita et al. (2012), Woodman and Luck (2007) and Moher and Egeth (2012) did not record neurophysiological data, the exact neuro-cognitive profile that underpinned their t-f-r findings was unclear.

1.1.1. Summary

The term t-f-r was coined by Woodman and Luck (2007) to explain emerging findings that target search could be accelerated by foreknowledge of salient distractor features. The behavioural nature of the paradigms described in this section excluded the possibility of explicitly identifying the discrete neuro-cognitive underpinnings of the t-f-r benefit. To establish whether a 'search and destroy' mechanism (see Moher & Egeth, 2012), or active avoidance of items with template matching features (see Woodmand & Luck, 2007) underpinned the findings, a neurophysiological technique would be required alongside behavioural measures.

1.1.2: *The event related potential technique*

Arita et al's (2012) findings are a useful example of why behavioural measures alone may not always be adequate to understand which specific cognitive functions have underpinned faster or slower responses. Event related potentials (ERPs) are thought to reflect postsynaptic potentials that are generated during neurotransmission. Electrical potentials appear to travel through the brain and skull to the scalp where they are recorded on the continuous electroencephalogram (EEG). As the EEG recording is taken at the scalp, postsynaptic potentials that are generated from the cortex are

picked up with better precision on the continuous recording. This is because fewer structures lie between the source of the signal and the electrode that receives the signal. For this reason, EEG as a research method is better suited for investigating activation that occurs over the cortex. A set of electrodes are placed on the scalp surface and a continuous signal detected by the electrodes is amplified and time-locked to the onset of one or more stimuli. Triggers (unique numbers) mark the points in time when a specific stimulus that represents a particular condition has been shown on the participants screen. This means that all the segments in the continuous EEG that are time locked to the onset of a particular trigger, can be averaged together. Signal averaging is the process of overlaying the time-locked signals associated with particular experiment conditions (indexed by the trigger) and for each moment in time (normally at 2, or 4 millisecond intervals) the signals at each of the related segments are averaged. By averaging the segments in this way, any 'noise' (fluctuations in the signal not associated with the experiment condition) will be averaged to zero so that what is left can be assumed to have occurred because of common neural activation associated with the experiment condition (stimulus/stimuli on the screen). The averaged segments for each participant are analysed with respect to the experiment conditions so that any common modulation to the ERP waveform can be used to help understand the neural mechanisms that underlie specific cognitive processes.

Averaged ERP waveforms consist of a number of positive and negative deflections which are typically referred to as 'peaks', 'waves', or 'components' (see Eimer, 1996; Luck, Woodman, & Vogel, 2000). In the current thesis the term component will be used. Components in the ERP waveform are usually labelled with a P, or N to specify positive or negative polarity, and a number is normally given to indicate the point in time after stimulus onset that a particular component normally peaks (e.g.,N170 is the label given to a negative polarity component that typically peaks around 170ms after the onset of a foveal presented face stimulus). The sequence of components that evoke following the onset of a stimulus indicate the order of neural processes that were triggered by the stimulus. Early sensory components emerge prior to components associated with attention and working memory. Specifically, the amplitude (magnitude of a signals response) and latency (point in time following onset of a stimulus) of the successive components can be used to measure the temporal course of cognitive processing. Because ERPs provide a continuous measure of neural activity as it reaches the cortex,

neural mechanisms which interpose the period between the onset of a stimulus and the participants response can be measured in order to provide a multidimensional perspective of cognition.

1.1.2.1: Summary

The current thesis will make use of the ERP technique to investigate the discrete neurocognitive profile that underpins the use of known distractor features for facilitating target search. This will be done by recording continuous electroencephalogram (EEG) alongside traditional behavioural measures (target identification speed and accuracy). The EEG recording will be analysed in terms of task-related processing that occurs during specific ERP components.

1.1.3: The N2pc ERP Component and its sub-components

the N2pc ERP component provides a spatially sensitive index of the covert deployment of visual attention. Typical N2pc tasks involve the selection of a target item that appears amongst distractors (Eimer, 1996; Luck & Hillyard, 1994a, 1994b; Woodman & Luck, 1999, 2003). The N2pc peaks at around 200ms post stimulus onset, and is larger over the contralateral (opposite) visual cortex with respect to the spatial location of the attended target. For left visual field targets the N2pc appears over the right visual cortex, for right visual field targets the N2pc appears over the left visual cortex. The lateralised response characteristics of the N2pc have made it popular for use in tasks measuring the direction (left or right) of attentional deployment with resolutely accurate temporal precision (Eimer, 1996; Luck & Hillyard, 1994a, 1994b; Woodman & Luck, 1999, 2003).

An important study by Hickey, Di Lollo, and McDonald (2009) used a novel two-item sparse search array and revealed that the N2pc component actually reflects the summed response of at least two other ERP components. With respect to a central fixation cross, item one appeared at top or bottom vertical midline position so that it could not influence spatially lateralised ERP activity. Item two appeared at one of 60°, 120°, 240°, or 300° lateral clockwise positions so that it alone would trigger the spatially lateralised ERP response. During the N2pc component interval, lateral item selection evoked

a contralateral negativity, subsequently termed the N_T component; whereas midline item selection which necessitated lateral item inhibition evoked a contralateral positivity (more positive amplitudes over the contralateral, versus ipsilateral hemisphere). The latter profile of response was subsequently termed the P_D component and its discovery paved the way for research focused on revealing both the sequence of and mechanisms by which distractor suppression occurs.

1.1.3.1: *Summary and General Research Question*

The N2pc component and its sub-components (N_T and P_D) will be measured with respect to possible modulation by task and t-f-r availability. The P_D subcomponent of the N2pc has been identified as reflecting stimulus suppression. Therefore, if attentional selection at the location of a t-f-r distractor is suppressed (consistent with Woodman & Luck's, 2007 suggestion), this should be characterised by the emergence of a P_D opposite the location of the t-f-r distractor. Alternatively, if t-f-r distractors are selected faster so that attention can then be more rapidly reallocated elsewhere (consistent with Moher & Egeths', 2012 search and destroy mechanism) then in comparison to non t-f-r distractors there should be an earlier N_T opposite t-f-r distractors prior to reallocation of attention towards the search target.

1.1.4 *ERP studies of templates-for-rejection*

A popular hybrid theory of distractor suppression was first outlined by Sawaki and Luck (2010). The Signal Suppression Hypothesis 'of controlled attentional capture' (SSH: Sawaki & Luck, 2010) postulates that bottom-up and top-down mechanisms can work in tangent. While salient items elicit a bottom-up attend-to-me priority signal that attracts attention, consistent with the Contingent Voluntary Orienting Hypothesis a top-down inhibitory mechanism can suppress the signal before it captures attention.

To test the validity of their Signal Suppression Hypothesis Sawaki and Luck (2010) employed a paradigm wherein rapid serial search of a cued region could contain a letter target, a target similar distractor defined as a smaller but otherwise identical letter, or a salient distractor that was a different

letter presented in red amongst otherwise green letters, or vice versa according to experiment block. An N2pc emerged from 200ms post-stimulus onset in response to the target and the target similar distractor when they appeared in the cued region, though was slightly reduced to the latter stimulus type. In contrast, a P_D component to the salient odd-colour-out distractor emerged from 100ms post-stimulus onset irrespective of whether the stimulus appeared in the cued, or non-cued region. The findings support that an N2pc (attentional selection) response was triggered by the target similar distractor as well as the target because, in-line with the Luck and Hillyard (1994b) definition of the N2pc component, both stimulus types triggered localising and binding of visual target features in the presence of additional distractors. The authors explained their P_D component findings through their Signal Suppression Hypothesis (SSH) 'of controlled attentional capture'. According to the theory, the salient odd-colour-out distractor elicited an early 'attend-to-me' priority signal that was actively suppressed to prevent the capture of attention by salient, but task-irrelevant singletons (Sawaki & Luck, 2010).

Recently, Gaspelin and Luck (2018) found that when a salient distractor item elicited a P_D component, participants also showed impaired recall of a letter contained in a probe that matched the previously suppressed item. This finding strongly supports that early P_D activation reflects active suppression of feature inputs and that inputs which match a learned distractor feature can be prevented from receiving selective attention processing.

1.1.4.1 *Summary*

The SSH predicts that attentional selection of t-f-r distractors can be actively suppressed. Both Sawaki and Luck (2010) and Gaspelin and Luck (2018) have provided empirical evidence to support the SSH. It is noted though, that the experiments which formed the bases of the SSH shared a common feature. The colour feature that formed the t-f-r was held constant in both experiments. It is therefore, of current interest to determine whether the SSH may be paradigm specific. This general research question will be answered by using paradigms that differ from those used by Sawaki and Luck (2010) and Gaspelin and Luck (2018) in various ways. It is expected that at least some caveats to the SSH will emerge.

1.1.5: ERP Dissociation Between Early and Late Distractor Suppression

Liesefeld, Liesefeld, Töllner, and Müller (2017) used a salient (very tilted bar) distractor and a less salient (less tilted bar) target to investigated the sequence of attention mechanisms that evoke to overcome distractor elicited capture. Variations of the search display presented one of these items on the vertical midline with the other at a lateral location, or the two items could either appear bilaterally (one item on each side of the display), or on the same side; or only the target would appear on the display at a lateral location. When the distractor was laterally presented and the target was on the midline, there was evidence of distractor evoked attentional capture as an N2pc (here termed $N_{D:}$ distractor negativity) was observed contralateral to the distractor; this was then followed by a $P_{D,}$ indicating subsequent distractor suppression. When the target was lateralised and the distractor was on the midline, there was evidence that the target was attentionally selected because an N_T (target negativity) was contralateral to the target; however, this emerged later than the N_D on lateral distractor trials, suggesting that on lateral target trials, the midline distractor had captured attention before attention was then redeployed to the lateral target. Unlike the previous trial type, lateral target selection was not followed by suppression. This suggests that suppression was necessary to actively terminate distractor evoked attentional capture, but was not necessary to terminate attentional selection of the less salient target. The finding that lateral target selection (N_T) occurred later than distractor elicited capture (N_D) suggests that stimulus-driven capture occurs early in the attention processing stream and post-capture suppression may be necessary for attentional selection of less salient target items (N_T). Notably, when there was no distractor present on the display the lateral target was selected more quickly than when a distractor was present on the midline; this further supports that salient items may initially capture attention and that top-down task-driven processing may only proceed after the initial stimulus-driven response has been suppressed.

Two further findings were of particular interest. The first was that on trials where the target and distractor appeared bilaterally, a very early N2pc emerged contralateral to the distractor; this N2pc then flipped so that there was a large contralateral negativity to the target. Additional calculations by the

authors strongly suggested that the flipped and substantially larger N2pc appeared to reflect the sum of target selection (N_T) and distractor suppression (P_D). This finding was of interest because although an 'N2pc flip' (term used by Jannati, Gaspar, & McDonald, 2013; McDonald, Green, Jannati, & Di Lollo, 2013) has previously been observed during serial search for multiple targets (Woodman & Luck, 1999), Liesefeld et al's. (2017) findings appear to be the first to demonstrate that the chain of ERP events that follow distractor elicited attentional capture can also account for the presence of an N2pc flip.

Liesefeld et al. (2017) also reported that faster RTs were linked with increased distractor suppression (enhanced P_D amplitude), suggesting that better distractor suppression allowed for more efficient target selection. Similar findings have been reported by others (e.g.,Gasper & McDonald, 2014; Sawaki & Luck, 2010); for example, Gasper and McDonald (2014) reported that distractors of equal salience to the search target were directly suppressed without initially capturing attention, and that more enhanced suppression (increased P_D amplitude) was associated with faster target identification. It should be noted that Gasper and McDonald (2014) held the salient distractors colour constant throughout experiment blocks. In another example, Jannati et al., (2013) reported evidence for direct suppression of a salient distractor (P_D), but only on fast response trials. Notably, Jannati et al's. (2013) salient distractor (red colour singleton) was in a difference dimension to the target (circle amongst diamonds); therefore, it is possible that Jannati et al's. (2013) salient distractor had also acquired t-f-r status and in-line with the possible paradigm specificity of the SSH, was also actively suppressed during early processing because t-f-r colour was held constant throughout the experiment.

The target and salient distractor in Liesefeld et al's. (2017) experiment were both of the same dimension (both tilted bars) which meant that salience was relational (defined in comparison to the surrounding inputs), therefore a specific dimension, or feature could not be actively suppressed. This suggests that when search distractors are defined by their relative salience, rather than a unique salient feature, distractor evoked capture may be more likely to occur before suppression of attentional selection at the distractors location Liesefeld et al's. (2017).

Indeed, according to Luck and Hillyard (1999) depending of the nature of the task and stimuli, attention can operate in a number of cognitive subsystems including early sensory analysis, object recognition and working memory.

1.1.5.1: *Summary*

Liesefield et al. (2017) found that a search distractor which was both physically salient and similar to the search target could not be actively suppressed. Instead, a profile of early attentional capture, followed by reallocation of attention towards the search target and active suppression at the location of the incorrectly selected distractor emerged. The pattern of effects reported by Liesefield et al. (2017) profiles a neurocognitive response consistent with Moher and Egeth's (2012) search and destroy mechanism.

1.1.6: Neural Competition

The second finding in the Liesefeld et al. (2017) study that was of current interest, was that as the distance between the target and salient distractor increased, response times (RTs) decreased. Similar findings were also reported by Gasper and McDonald (2014). These findings can be accommodated by previous work relevant to the role of selective attention. Luck, Girelli, McDermott, and Ford (1997) proposed that neural ambiguity arises when items appear in close proximity because cells in visual cortex are organised so that they topographically represent the spatial location of visual inputs. Thus, when inputs are in close proximity, activation of a cells receptive field could be driven by either of the closely positioned inputs. This results in neural ambiguity with respect to which input is being represented. Luck et al. (1997) proposed that the role of selective attention in the ventral object recognition pathway is initially to resolve this neural ambiguity.

Resolution to neural ambiguity according to Desimone and Duncan's (1995) BCT, is achieved through a series of bottom-up and top-down interactions. Specifically, BCT states that objects in the visual field compete for representation in visual cortex by means of mutual neural suppression (also see Desimone & Ungerleider, 1989). While bottom-up (stimulus-driven) influences initially bias the

competition for representation towards the more physically salient item, top-down task set can influence this process so that items which are task-relevant are represented in visual cortex. Importantly, the findings from a number of studies suggest that the first endogenous (top-down) shift of attention toward a search target occurs after stimulus competition has been resolved (e.g., Hickey, McDonald, & Theeuwes, 2006; Sawaki & Luck, 2010; Theeuwes, 1991; for reviews, see Burnham, 2007; Rauschenberger, 2003; Theeuwes, 2010a). Hickey and Theeuwes (2011) explain that when a target and distractor appear in close proximity, initial stimulus-driven bias in favour of the salient distractor increases representation of the distractor in visual cortex which automatically suppresses representation of the target; this then has to be corrected by top-down control networks so that the target is represented in visual cortex, but this corrective process takes time. When a target and distractor appear further apart, they activate few of the same receptive fields. As a result, neural ambiguity is reduced and stimulus competition effects decrease. Any misallocated distractor enhancement could be quickly corrected because target representation would not have been additionally suppressed (also see Mounts, 2000 a, b for a similar explanation).

1.1.6.1: *Summary*

Taken together, the findings with respect to stimulus competition suggest that a) speed of target search may be slower when the search distractor is more, relative to less salient than the search target, and b) this effect may be further enhanced when target and distractor stimuli appear in close proximity, relative to when they appear further apart.

1.1.7 *Emotion and Modulation of Attention*

Early detection of facial emotion is critical for survival. Direct sub-cortical routes involving magnocellular pathways and the amygdala can rapidly detect threat and influence ventral processing. Whalen, Rauch, Etcoff, McInerney, Lee, and Jenike (1998) reported enhanced amygdala activation for fearful faces despite these faces being presented below conscious awareness. In a facial judgement task Adolphs, Tranel, and Damasio (1998) found patients with bilateral amygdala damage judged faces to be more trustworthy and approachable when compared to judgements of the same faces made by a

control group; this highlights the importance of the amygdala in social judgements which are key to social success, not least survival.

Vuilleumier, Armony, Driver and Dolan (2003) showed participants face images that contained only high, only low, or broad spatial frequency information (HSF, LSF, BSF respectively). While BSF stimuli were normal, fully intact faces, HSF faces contained only the finer grained rich edge and surface detail, such as eye, mouth and forehead contours that could be used for identification of an individual's age, sex, emotional expression, or identity (also see Bruce, Healey, Burton, 1991; Hill, Schyns, & Akamatsu, 1997). The LSF faces contained no fine-grained detail; these faces provided global, configural information of shadow-related feature positions that would allow only coarse information, such as sex, or emotion to be detected. In a separate experiment, sex identification was found to be equally well derived from HSF and LSF faces (Schyns & Oliva, 1999). Vuilleumier et al., (2003) carried out event-related functional magnetic resonance imaging (fMRI) while participants reported the sex of BSF, HSF and LSF faces with fearful or neutral expression. Amygdala activation was enhanced for BSF and LSF, when compared with HSF faces. Moreover, LSF fearful faces were associated with superior colliculus and pulvinar activation, suggesting that sub-cortical routes may input directly to the amygdala for rapid threat detection. On the other hand HSF and BSF faces were associated with increased activity in bilateral fusiform (the fusiform has been well documented as involved in identification processing, e.g., Kanwisher, McDermott, & Chun, 1997) and inferior temporo-occipital cortex. Repetition effects on bilateral anterior fusiform regions, right parietal cortex and insula, were observed for BSF and faces initially presented in HSF, but not LSF; this was irrespective of emotional expression. What is more, when a separate group were asked to rate the same faces with respect to degree of fearfulness, lower ratings were given for LSF than HSF and BSF faces. Taken together, these findings suggest LSF information gains direct access to the amygdala via sub-cortical superior colliculus and magnocellular tecto-pulvinar pathways (see Morris, Öhman, & Dolan, 1998 for similar findings) for rapid response to threat; whereas detailed analysis of HSF structural information may be chiefly executed in fusiform cortex via parvocellular inputs to ventral cortical pathways.

Similar findings were conferred by Eimer and Holmes (2002). They reported that fearful, relative to neutral faces evoked early neurophysiological modulation from 120ms post-face-onset; whereas another neurophysiological response, (the face sensitive N170 component) was not modulated by facial emotion; these findings provide confirmatory support that rapid emotion detection precedes and is at least partially separate to more detailed analysis of facial structure. However, with respect to attention, Holmes, Green and Vuilleumier (2005) reported evidence that rapid fear detection can prepare attention networks to respond faster at the location of detected fear. In Holmes et al's. (2005) task participants reported the orientation of a bar target that immediately replaced either fearful or neutral LSF or HSF faces. Faster responses were recorded to fearful, than neutral replacements, and this effect was observed for fast presentation of LSF, but not HSF faces. The data strongly support a role for rapid fear detection in preparing attention networks. This attentional prioritisation of inputs with emotional significance has been demonstrated through other research findings (e.g.,Bretherton, Eysenck, Richards, & Holmes,. 2017; Csathó, Tey, & Davis, 2008; Eastwood, Smilek, & Merikle, 2001; Fenske, & Eastwood,. 2003; Fox, Russo, Bowles, & Dutton,. 2001; Fox, Russo, & Dutton,. 2002; Holmes, Bradley, Kragh Nielsen, & Mogg, 2009); for example, Csathó et al. (2008) evidenced that early threat detection appeared to preferentially prime visuomotor processing toward the periphery, and this early threat detection response appeared to involve superior colliculus activation that showed a nasal, versus temporal hemifield asymmetry.

1.1.7.1: *Summary*

Facial emotion and threatening valence in particular has been shown to receive attentional prioritisation. Neuroimaging studies have provided evidence that early preparation of selective attention networks is achieved through feedforward processing by subcortical neural circuitry involved in early threat detection. Although subcortical threat detection is rapid, explicit identification of threat appears to involve higher order neural circuitry which takes longer. Previous findings (Sawaki & Luck, 2010; Sawaki, Geng, Luck, Moore, & Zirnsak, 2012) suggest that in some instances, such as when the salient feature of a distractor stimulus is known, bottom-up salience driven and top-down goal driven factors can interact so that selection of items containing the salient feature is prevented. It is not yet

known whether attentional selection could also be supressed for stimuli that are salient due to a socio-motivational feature such as threatening emotional expression.

Chapter 2: Neutral versus angry templates-for-rejection and selection

2.1: Introduction

We typically encounter complex and cluttered visual environments. Our capacity to process the range of visual inputs efficiently is limited; therefore, visual attention is required to select and process only the most relevant inputs (Wolfe & Horowitz, 2004). Theories of attention propose that interactions between bottom-up (automatic) and top-down (controlled) attention underpin the process of selecting task-relevant stimuli (e.g., Bundesen, 1990; Desimone & Duncan, 1995; Neisser, 1967; Treisman, 1988; Wolfe, 1994). Some neural theories of visual attention (e.g., Bundesen, 1990; Bundesen et al., 2005; Desimone & Duncan, 1995) suggest a role for top-down guidance in configuring mechanisms of perceptual attention to preferentially select objects with target matching features. In addition to theories regarding the neural processing that underpins target selection, recent hypothesis testing has surrounded the neural processing behind distractor suppression; in particular, how we suppress attentional selection of salient but task irrelevant stimulus inputs.

Woodman and Luck (2007) found that when participants remembered a colour feature for post-trial memory tests, they performed better during a search task when the colour maintained in visual working memory (VWM) appeared as a distractor during target search, compared to when it did not. The finding suggests that features known to be task-irrelevant may be used to avoid processing feature-matching non-targets in our field of view. This study was one of the first to demonstrate that VWM maintained features do not always bias allocation of attention toward feature matching inputs. The authors coined the term ‘templates-for-rejection’ (t-f-r) to describe feature guided avoidance of items that match the contents of VWM.

The idea that visual attention can be biased away from nontarget items appears to be compatible with Bundesen’s Neural Theory of Visual Attention (NTVA) (see Bundesen, 1990; Bundesen et al., 2005) which states that target representations maintained in visual working memory (VWM) during visual search interact with attention networks in inferotemporal cortex to set high

attentional weights for inputs that match target features. If VWM representations can be used to dynamically set high attentional weights for feature matching inputs, then it may logically follow that VWM representations of known salient distractor features may also be used to lower attentional weights for inputs that match those features.

Indeed Arita et al. (2012) suggested this extension of NTVA to explain the findings derived from a set of t-f-r tasks. In the Arita et al. (2012) paradigm, separate experiment blocks pre-cued the colour of the target, the distractor, or an irrelevant colour that would not appear during target search. Response times were fastest on target cue trials, though a response speed benefit also emerged on distractor cue, versus irrelevant cue trials. Initially, Arita et al's. (2012) findings appeared to confer support for Woodman and Luck's suggestion, as distractor cues seemed to be used to avoid the non-target items; however, because stimuli presented during search appeared in only two colours and each occupied its own side of the array, an alternative account for the findings may be that the cue-matching distractors were located, then rapidly dismissed so that the stimuli on the other side of the array would be searched for the target. This alternative proposal suggests that the known distractor feature was not down-weighted; instead participants had to first select the side of the array that appeared in the cued colour, then redeploy attention to the opposite side of the array to find the target. Unfortunately, because these findings were derived from behavioural data only, it was not possible to confirm which neural process had underpinned the observed t-f-r benefit to target identification speed.

Event Related Potentials (ERPs) have since been used to investigate the neural mechanisms (neuro-mechanisms refer to structures in the nervous system that activate to perform specific cognitive functions) that underlie t-f-r because the method is able to provide a temporally accurate measure of neural responses that occur directly from discrete cognitive processes. Crucially, the N2pc has been employed as a spatially sensitive index of the covert deployment of visual attention in tasks involving the selection of a target stimulus amongst distractor stimuli (Eimer, 1996; Luck & Hillyard, 1994a, 1994b; Woodman & Luck, 1999, 2003). The N2pc elicits approximately 200ms after stimulus onset, and is maximal over the visual cortex contralateral (opposite) to the spatial location of the attended target. If the left visual field is attended, the N2pc appears over the right visual cortex, and vice versa.

The spatial characteristics of the N2pc have made it a useful tool for measuring the direction (left or right) of attentional deployment with resolutely accurate temporal precision (Eimer, 1996; Luck & Hillyard, 1994a, 1994b; Woodman & Luck, 1999, 2003).

Recent work focussed on the N2pc (Hickey et al., 2009) suggests that the component reflects the sum of multiple attentional mechanisms. Hickey et al. (2009) employed a two-element sparse search array task, with one stimulus presented on the vertical meridian and the other laterally to the left or right of this central mid-line. Participants were required to identify either the centrally or the laterally positioned stimulus, whilst ignoring the other stimulus. The ERP wave-forms that were reported demonstrate three important findings: a) *When targets were presented laterally* with distractors on the vertical meridian an independent *negative* going ERP component termed the 'target negativity' (N_T) was observed over lateral and ventral areas; b) *When distractors were presented laterally* with targets on the vertical meridian an independent *positive* going ERP component termed the 'distractor positivity' (P_D) was observed over dorsal and medial areas; c) *When targets and distractors were both presented laterally,* a negative going ERP component was elicited at a *decreased* amplitude to that of the N_T, which reflected the normal response profile of the N2pc. Hickey et al. (2009) subsequently proposed that the P_D reflects direct suppression of the cortical representation of distractor stimuli, whilst the N_T reflects attentional selection of targets. Importantly, because an N2pc was observed when targets and distractors were both presented laterally, the researchers concluded that the P_D and N_T reflect separate attentional mechanisms which summate, determining the response profile of the N2pc.

Hickey et al's. (2009) findings have improved understanding of how changes in the amplitude of the N2pc component can reflect interactions between inhibition and selection networks during visual search; for example Liesefeld et al. (2017) found that an initial N2pc contralateral to a salient distractor, then flipped and also increased in laterality divergence contralateral to the less salient target. These findings demonstrated that the salient distractor had initially captured visual attention (N2pc contralateral to salient distractor), but was then actively suppressed (P_D contralateral to the salient distractor) so that attention could be redeployed to a less salient target (N2pc contralateral to the target). In addition, the summed response of salient distractor suppression and less salient target

selection was shown to have been responsible for the increased laterality divergence of the flipped N2pc. Liesefeld et al's. (2017) findings usefully showed how N2pc laterality divergence and direction can be used to demonstrate both where attention has been allocated, and the magnitude of the response. It is notable though, that Liesefeld et al's. (2017) findings showed capture of attention by the salient distractor despite prior knowledge of the distractors characteristics. At first glance, this finding appears to contradict t-f-r theory put forward by Woodman and Luck (2007); however, t-f-r theory proposes that salient *non-target features* can be used to avoid misallocation of attention. In Liesefeld et al's. (2017) study the salient distractor feature (very rightward tilted bar) was in the same dimension as the less salient target feature (slightly leftward tilted bar). Thus, the target and distractor features shared the same feature dimension which likely prevented a t-f-r response.

In a study by Jannati et al. (2013) participants searched for a target that was defined by shape. A salient red colour singleton distractor also appeared during search. On fast response trials, an early P_D component emerged contralateral to the salient distractor, demonstrating that attentional capture had been actively suppressed when its salient feature was in a different dimension to the search target.

So far, it has been shown that when a salient feature is learned (e.g., Jannati et al., 2013), or cued (Arita et al., 2012; Woodman & Luck, 2007) it may be maintained in VWM for use as a t-f-r. Moreover, some ERP studies have shown that at least sometimes, distractors which match the t-f-r feature can be actively suppressed (e.g., Jannati et al., 2013). Sawaki and Luck (2010) also demonstrated evidence that attentional capture by a salient distractor was actively suppressed when participants knew what the salient non-target feature was prior to the onset of visual search. To explain their finding of an early P_D component contralateral to the location of the salient non-target, the authors proposed the Signal Suppression Hypothesis 'of controlled attentional capture' (SSH). This theory was proposed with respect to the neural mechanisms that underlie active suppression of early attentional capture. Specifically, the authors stated that salient items elicit an 'attend to be priority signal' which can be actively suppressed prior to the onset of attentional capture.

Thus far, the P_D has been put forward as an index of distractor inhibition (e.g., Hickey et al., 2009; Sawaki & Luck, 2010), but the role of the P_D in attentional selection has not been addressed. Sawaki et al. (2012) demonstrated that attentional selection of targets (N2pc to target) was followed directly by inhibition of targets (P_D). It is likely that the P_D not only indexes inhibition of salient distractors, but also the control of neural networks involved in attentional selection of targets. Specifically, the findings reported by Sawaki et al. (2012) suggest that attentional selection networks are not left to passively fade after task completion, but are actively terminated to free-up attentional resources.

The research to date, has shown that when colour singletons have been used to investigate the neural underpinnings of t-f-r, findings seem to indicate that early active suppression can prevent attentional capture by salient distractors when the salient feature is known prior to the onset of the search task; though more research is needed to investigate what the limitations of t-f-r utility are. A notable limitation with respect to the body of work that exists, is that the neural dynamics which underpin t-f-r have been investigated almost exclusively using colour singleton search tasks. Colour singletons are very useful for experiments in cognitive neuroscience because they allow a high level of experimental control; however, real-world visual environments almost always present more complex visual processing challenges that rarely rely solely on attentional control of simple colour singletons. Therefore, it seems pertinent to begin investigation into whether and how real world items may be used as t-f-r. This is an important area for investigation because navigation of real-world environments may often require that humans avoid distraction by inputs that are highly salient, but also irrelevant to current goals. The first research question of the thesis asks whether avoiding attentional capture by real world items is accomplished by actively suppressing known non-relevant inputs (as suggested by SSH), or by a mechanism involved in rapid redeployment of attention following early attentional capture by real world items (in line with Liesefeld et al's., 2017 findings).

For the purpose of investigating neural dynamics associated with real-world t-f-r utility, the first experiment of the thesis will employ photographs of neutral, angry, sad, surprised, disgust and happy faces as the search stimuli. In particular, neutral and angry facial valence will be employed as t-f-r or

selection (t-f-s) depending on the experiment block. This will draw apart any differences in t-f-r utility when real world templates are socially salient (neutral template), versus socially and emotionally salient (angry template). This is because emotional valence has been shown to capture attention.

In a dot probe paradigm Holmes et al. (2009) presented angry/neutral and happy/neutral face pairs; one face within each pair was then replaced by an arrow (the dot probe), with participants indicating the type of target that appeared, (either up or down pointing arrow). The behavioural data showed faster responses when probes replaced emotional faces, compared to neutral faces, suggesting that emotion attracted attention preferentially. The findings of a number of other studies (e.g., Batty & Taylor, 2003; Pourtois, Grandjean, Sander, & Vuilleumier, 2004; Pourtois, Thut, de Peralta, Michel, & Vuilleumier, 2005; Ohman, Lundqvist & Esteves, 2001; Vuilleumier & Schwartz, 2001a, 2001b) have demonstrated the capacity for emotion, particularly threat-related stimuli, to evoke attentional prioritisation. Mogg and Bradley (1999) demonstrated rapid attentional prioritisation toward threat-related stimuli despite presenting stimuli below the threshold for conscious awareness. Other research has demonstrated a delay in attentional disengagement from sources of threat (e.g., Fox et al., 2001; Fox et al., 2002; Yiend & Mathews, 2001). Stimuli with high emotional salience, particularly threat, have thus far been shown to exogenously capture and engage attentional resources (e.g., Holmes et al., 2009; Mogg & Bradley, 1999; Fox et al., 2002; Yiend & Mathews, 2001).

Prioritisation of threat has a clear role in self-preservation as bottom-up capture by threatening stimuli may facilitate a faster response to threat in the environment (see Csathó et al., 2008; LeDoux, 1996; Ohman, Flykt, & Lundqvist, 2000). However, from a clinical perspective maladaptive neuro-mechanistic responses concerning attention networks in relation to threatening stimuli have been implicated in the cause and maintenance of anxiety disorders (e.g., Clark & Wells, 1995; Mathews & Mackintosh, 1998; Mogg & Bradley, 1998). Notably, Eysenck, Derakshan, Santos & Calvo (2007) reported evidence for recruitment of additional neuro-mechanistic systems when attention processes were executed under threatening or stressful conditions. There is a need to investigate at a mechanistic level, how neural networks involved in attention, are affected by the presence of

threatening stimuli (e.g., Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007; Mogg & Bradley, 1998).

For experiment one, each trial will present two faces which will appear bilaterally, either side of a central fixation cross. Depending on the experiment block, one face will always depict neutral valence (neutral template blocks), or angry valence (angry template blocks), and the other face will depict sad, surprised, disgusted, or happy valence at equal probability. For the task, participants will report the sex of the non-neutral face (neutral template-for-rejection block), or the non-angry face (angry template-for-rejection block). For comparison, the sex of the neutral, or angry face (neutral and angry template-for-selection blocks, respectively) will be reported in separate blocks. Identification of sex was used because previous findings have shown that sex is discriminated equally during rapid sub-cortical emotion processing as well as during fine grained facial identity processing (see Schyns & Oliva, 1999; Vuilleumier et al., 2003). Thus, the use of sex discrimination would prevent any processing bias being the result of the categorisation task, rather than the t-f-r task. On each trial a template-matching face will appear beside either a happy, sad, surprised, or disgusted face. Electroencephalography will be recorded while participants perform the experiment so that ERPs can be time-locked to the onset of the faces, and subsequently compared with the accuracy and response speed data associated with each of the experiment conditions.

The first experiment of the thesis aims to investigate: 1) What the impact of emotionally salient distractor stimuli will be when angry, versus neutral valence is utilised as a template-for-selection. An N2pc, followed directly by a P_D to template-matching targets would indicate attentional selection, followed by active termination of attentional selection to template-matching targets (see Liesefeld et al., 2017; Sawaki et al., 2012). Alternatively, an N2pc that gradually attenuates would indicate that template-matching targets were allocated enhanced processing resources, encouraging maintenance of attentional selection towards stimuli containing the template-matching feature (see Bundeson et al, 1995; 2005); **2)** What will be the impact of emotionally salient target stimuli when angry, versus neutral valence is utilised as a template-for-rejection. A P_D contralateral to template-matching distractors would be in line with Sawaki and Luck's (2010) SSH, demonstrating active

suppression of the “attend-to-me” priority signal elicited by template-matching distractors. Alternatively, an ‘N2pc flip’ (term used by Jannati, et al., 2013; Liesefeld et al., 2017; McDonald et al., 2013; Woodman & Luck, 1999) that is first contralateral to template-matching distractors, then contralateral to emotional valence targets would be in-line with post-capture neural dynamics reported by Liesefeld et al. (2017), demonstrating that stimuli with template-matching distractor features initially capture attention before capture is actively suppressed and attention redeployed to the target.

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2.2: *Methods*

2.2.1: *Pilot Study Methods*

A pilot study was carried out to gage optimum time constraints for stimulus presentation and inter-trial interval (ITI). It was important within the paradigm to ensure that task difficulty was high, whilst remaining at a level that would ensure an adequate number of correct trial responses for ERP analysis. Time constraints resulting in 85-90% correct responses were required for the main experimental paradigm.

2.2.1.1: *Participants*

The participants (4 male; mean ± SD age = 29 ± 7.45 years) were 5 right handed, healthy volunteers with normal or corrected to normal vision.

2.2.1.2: *Stimuli and Procedure*

The stimuli, apparatus and procedure used in the pilot study were identical to those used in the main experiment (see main experiment- methods). However, duration of stimulus presentation and ITI were varied across participants.

2.2.1.3: *Pilot Results*

Mean Reaction Times (RT) and % Accurate Responses (Acc) according to Condition and Experiment Time Constraints.

Time Constraints		Condition									
Stimulus Presentation Duration	Inter Trial Interval	Select Angry		Inhibit Angry		Select Neutral		Inhibit Neutral		Total	
		Accuracy %	Mean RT	Accuracy %	Mean RT	Accuracy %	Mean RT	Accuracy %	Mean RT	Accuracy %	Mean RT
500ms	800 - 1100 ms	78%	999ms	67%	1165ms	42%	1054ms	90%	905ms	69%	1031ms
700ms	1700 - 2000 ms	89%	1416ms	75%	1540ms	85%	1058ms	77%	1219ms	82%	1308ms
700ms	1500 - 1800 ms	88%	1068ms	91%	1167ms	98%	969ms	96%	788ms	93%	998ms
500ms	1500 - 1800 ms	79%	765ms	79%	913ms	87%	697ms	81%	588ms	82%	741ms
500ms	1500 - 1800 ms	88%	1163ms	92%	1252ms	95%	1047ms	96%	1052ms	93%	1129ms
Total		84%	1082 ms	81%	1207ms	81%	965ms	88%	910ms	84%	1041ms

Figure 2.1 The first two columns show time constraints applied to individual participants. Separate rows show Acc and RT within each condition. The two left-most columns show Acc and RT averaged across conditions for each participant. Rows four and five, show average Acc (82% and 93%) and RT (741ms and 1129ms) for stimulus presentation duration (500ms) and Inter Trial Interval (1500 – 1800 ms), selected for the main experiment paradigm.

2.2.2: *Main Experiment- Methods*

2.2.2.1: ***Participants***

A statistical power analysis was performed for sample size estimation, with statistical values based on previous published research (Holmes et al., 2009) where a sample of (N = 17), was used for a 2 x 2 x 2 x 3 repeated measures ANOVA. The effect size and partial eta squared (F = 3.25, ηp^2 = .17) was significant with an alpha and power of (p < .05, power = .80). The projected sample size (calculated using GPower 3.1.9.4) with this effect size was N = 18 for the specified within group comparison. A sample size of N > 18 was therefore, sought for the purpose of the present 2 x 2 x 2 x 4 repeated measures ANOVA. It was considered that this would allow for expected attrition.

For experiment one, a relatively large sample of twenty five healthy volunteers gave informed consent before beginning the experiment. Attrition was higher than expected as nine participants were excluded: four due to < 70% accuracy, a further four due to extensive accepted trial differences between conditions, and one due to excessive eye movements (see appendix 1 for details). Of the remaining sixteen healthy volunteers, all reported normal or corrected-to-normal vision. Fourteen of 16 participants (7 male; mean and SD age = 27.25 ± 5.93 years) were right handed. The experiment was performed in compliance with The University of Roehampton ethical and research guidelines and was approved by the University ethics committee.

2.2.2.2: ***Stimuli and Apparatus***

Face stimuli used for the experiment trials consisted of pairs of laterally presented greyscale photographs of eight individuals (4 male, 4 female) taken from the NimStim Set of Facial Expressions (available at http://www.macbrain.org/faces/). Normative data (Tottenham et al., 2009) found the mean proportions of correctly identified angry faces (M=87%, SD=.16) and neutral faces (M=87%, SD=.09) were comparable.

Each face pair comprised two of eight possible face IDs (1 male, 1 female), with one photograph portraying a neutral expression (select/inhibit neutral blocks) or angry expression

(select/inhibit angry blocks) and the other photograph portraying a sad, surprised, disgusted, or happy expression at equal probability. Individual face pair configurations (256 different ID x emotion x position (left/right) configurations) were presented once, in random order for each participant within each block. Participants completed four experiment blocks (angry select/inhibit, neutral select/inhibit), totalling 1, 024 experiment trials. Sex of the target face was presented at equiprobable left or right locations. An additional set of eight greyscale photographs (different individuals (4 male, 4 female)) with expressions of fear and calm were taken from the NimStim set for use in practice trials. Practice trial face pairs (16 different ID x emotion x location configurations) consisted of two individuals (1 male, 1 female) with one photograph portraying a fearful expression and the other a calm expression. Face stimuli for the practice and main experiment trials were cropped in an oval shape (4.29cm wide × 5.34cm high) to remove hair or clothing and subtended a visual angle of approximately 4.5° x 4.5°. The centres of the faces were presented 5.55 cm from a grey central fixation cross (6mm subtending a visual angle of approximately 0.4°) against a black background. The faces within each face pair were equated for mean luminance and root mean square (RMS) contrast energy. Mean luminance energy was calculated for each face stimulus, then equated across all face stimuli. Total RMS energy for each luminance equated face was then calculated, and the luminance value at each pixel from each face was divided by that value (using standard routines in Matlab 6), resulting in a mean luminance value of 7.83 cd/m2, and Michelson contrast of .934.

Participants were seated in a dark, sound-attenuated cabin, 70 cm from a 17-in. ViewSonic G220f computer screen with a refresh rate of 75Hz, connected to a Dell precision Pentium IV computer. E-Prime Psychology Software 2.0 (Schneider, Eschman & Zuccolotto., 2002) was used for stimulus presentation and response collection. Responses were indicated via a purpose built response box.

2.2.2.3: *Procedure*

Experiment blocks began with a stimulus display (see Figure 2) of eight angry faces (select/inhibit angry blocks), or eight neutral faces (select/inhibit neutral blocks) to enhance visual

working memory representations of the to-be-remembered stimuli. Trials (see Figure 3 for example trial sequence) started with a central fixation cross for 500ms, followed by a face pair (see Stimuli and Apparatus for face pair configurations) for 500ms. A blank screen replaced the face pair for 1500-1800 ms. Responses were collected until offset of the blank screen.

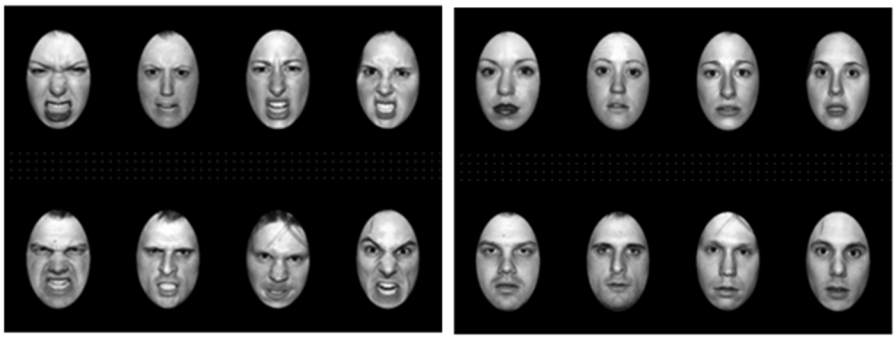


Figure 2.2 Stimulus displays shown prior to angry select/inhibit (left) and neutral select/inhibit (right) conditions.

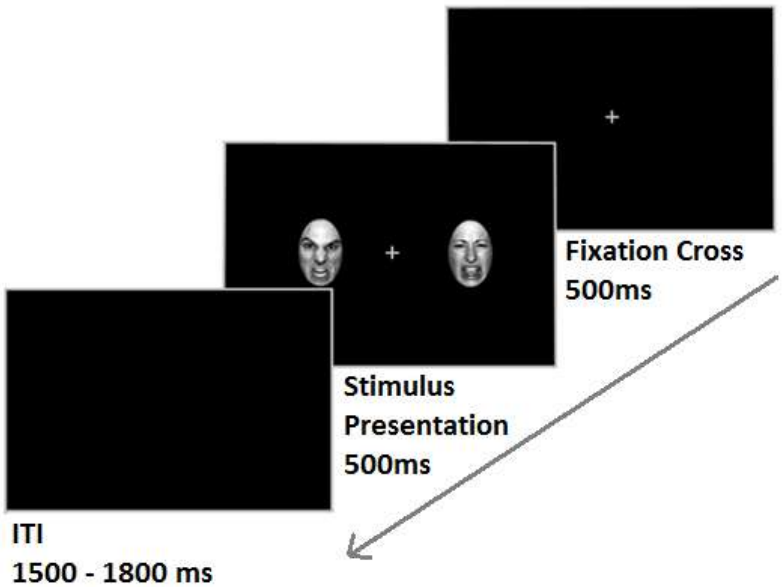


Figure 2.3 Example of angry select/inhibit trial sequence with timings depicted. *Stimuli not to scale.*

Half the participants were randomly allocated to receive angry blocks prior to neutral blocks. The remaining participants received neutral blocks prior to angry blocks. An instruction screen directed participants to indicate as quickly and accurately as possible, the sex of the angry face (select block), or the non-angry face (inhibit block). Instructions were adapted for neutral select/inhibit blocks. Sex of the target face was indicated using the index and middle finger of the dominant hand and buttons one and two (counterbalanced across participants) on a purpose built response box. Approximately every 68 seconds participants received an on-screen instruction to take a short break and press the space-bar when ready to continue.

Practice trials: The angry and neutral eight element stimulus displays used prior to main experiment blocks were adapted to calm and fearful expressions for the practice blocks. Participants completed 32 practice trials ((select/inhibit fearful face = two blocks with 16 trials per block), or (select/inhibit calm face = two blocks with 16 trials per block)) where accuracy and response time feedback was given, before beginning the main experiment. E-Prime ran one sample of 16 trials (presented in random order), reset for each participant. Fearful face blocks and calm face blocks were counterbalanced across participants.

2.2.2.4: *EEG Data Acquisition*

EEG was recorded from 32 Ag-AgC1 electrodes (Fp1, Fp2, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T8, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, O1, Oz, O2, PO7, PO8, PO9 and PO10 (according to the 10-20 system)), referenced on-line to the vertex and then re-referenced off-line to the average of the left/right ear lobes. Horizontal EOG (HEOG) was recorded bipolarly from the outer canthi of both eyes. See Figure 3 for electrode layout. All electrode impedances were kept below 5 kΩ; EEG and EOG were digitised with a sampling rate 250 Hz. The EEG was filtered online at d.c. to 100 Hz with vertex (CZ) as the online reference. Following EEG recording, data were digitally filtered offline with a bandpass of .3 Hz (24 db/oct) to 30 Hz (24 db/oct; zero-phase shift) using Neuroscan software (version 4.5). EEG and HEOG were then epoched into 600ms intervals, from 100ms before (pre-stimulus baseline) to 500ms after face pair onset. Trials with lateral eye movements (HEOG exceeding ± 30 μV) and trials with eyeblinks

(Fp1/Fp2 exceeding ± 60 μV), or other artifacts (voltage at any electrode exceeding ± 80 μV) measured in each epoch were excluded from the analysis. Epochs were then re-referenced to the average of A1 and A2 ear lobe electrode locations.

Separate averages were computed for all combinations of task type (select vs. inhibit), target template valence (angry vs. neutral), separately for left and right presentation locations. Contralateral ERPs were computed as the average of the left (PO7) and right (PO8) hemisphere electrodes when target templates were presented to the opposite visual field, right and left respectively. Ipsilateral ERPs were the average of PO7 and PO8 when target templates were presented to the same sided visual field, left and right respectively. Electrode PO7 and PO8 were selected for analysis because contralaterality effects were maximal at those sites. The ERP factors submitted for analysis were target template valence (angry vs. neutral), task (select vs. inhibit), laterality (contralateral vs. ipsilateral), and component (180-230 ms, 230-280 ms, 280-330 ms, 330-500 ms see section on ERP components below)).

2.2.2.5: *ERP Components*

Visual inspection of the ERP waveforms, combined with previous research on contralateral components such as the N2pc, P_D and SPCN (e.g., Grubert & Eimer, 2016; Hickey et al., 2009; Holmes et al., 2009; Holmes, Mogg, de Fockert, Kragh Nielson & Bradley, 2014; Woodman & Luck, 2003), resulted in identification of four ERP component time-windows that best represent the modulations of contralaterality effects (i.e., in attention processing) elicited by the current paradigm, with particular focus on the ERP wave-form associated with the Select Neutral condition. Component time-windows were as follows: 180-230 ms, 230-280 ms, 280-330, and 330-500 ms.

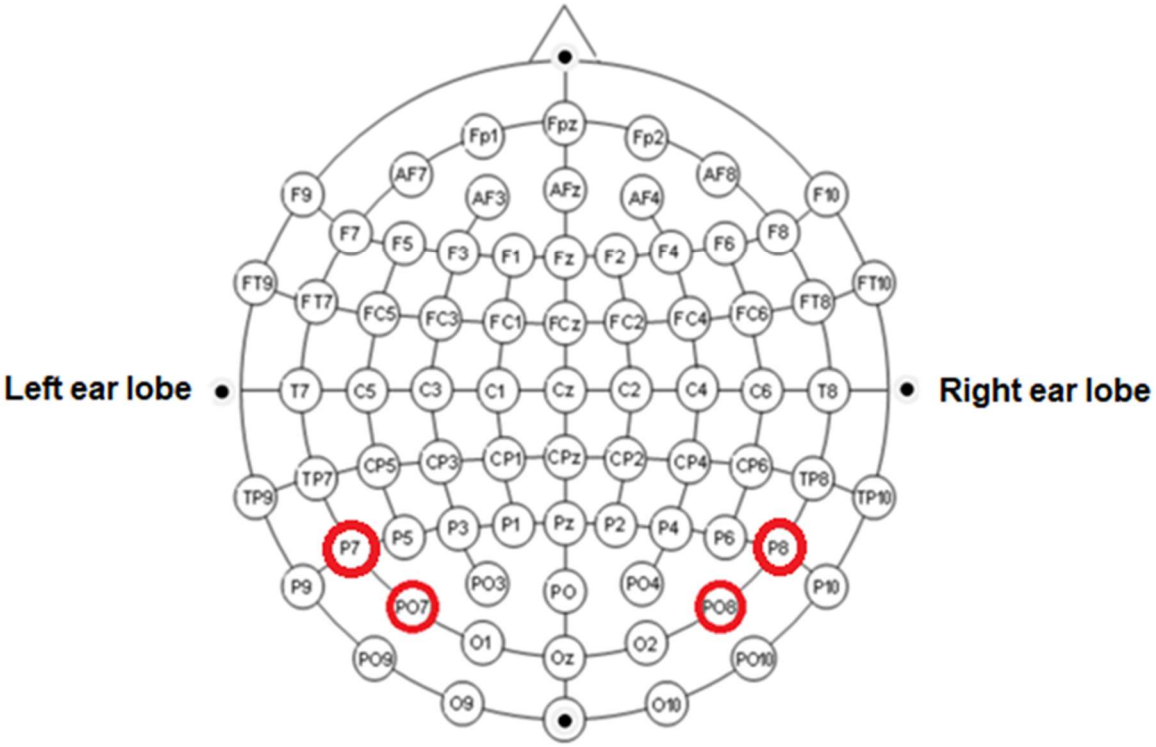


Figure 2.4 Adapted from EASYCAP GmbH: www.easycap.de. Electrode cites PO7 (left) and PO8 (right) marked in red, used for statistical analysis of mean amplitudes.

2.3: Results

2.3.1 *Behavioural Results*

Mean percentage accurate responses (Acc) and mean reaction times (RT) for each participant were entered into a repeated measures analysis of variance (ANOVA) with the factors: task (select vs. inhibit) and template valence (angry vs. neutral). Note that for the select conditions, participants were given a template-for-selection; no distractor information was available. For the inhibit conditions, participants were given a template-for-rejection; no target information was available.

2.3.1.1*: **Accuracy***

See figure 4 for mean percentage accurate responses. There was lower overall accuracy in response to angry (M = 82.5%, SD = 7.71%), relative to neutral (M = 88.5%, SD = 7.41%) valence conditions; ($F(1,15) = 29.357$, $p < .001$, $\eta p^2 = .662$). Contrastingly, accuracy associated with select conditions (M = 85.5%, SD = 7.49%) was equivalent to that associated with inhibit conditions (M = 85.5%, SD = 7.63%); ($F(1,15) = 0.02$, ns, $\eta p^2 = .001$). There was no valence x task interaction (p>.05).

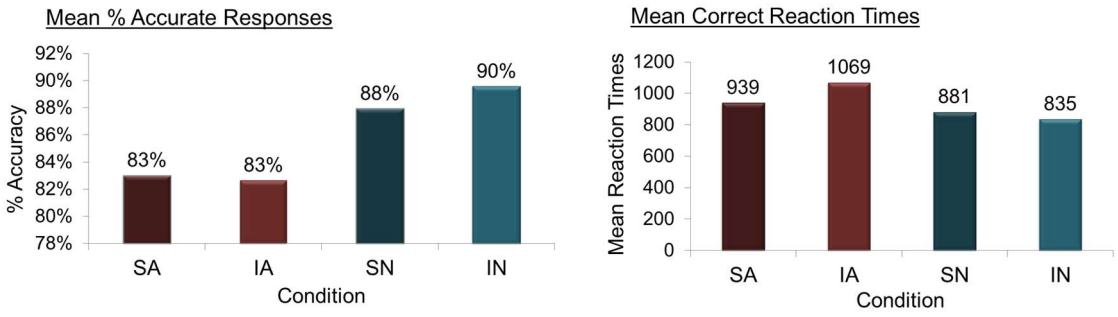


Figure 2.5 Graph illustrating reaction time (RT) and accuracy (Acc) scores for select (S) versus inhibit (I), angry (A) versus neutral (N) conditions.

2.3.1.2*: Response Times*

See figure 4 for mean reaction times. Reaction times were slower overall in response to angry (M = 1011, SD = 145.42), relative to neutral (M = 855.5, SD = 122.47) valence conditions ($F(1,15)$ = 98.073, $p < .001$, $\eta p^2 = .867$), and faster overall for select (M = 914.5, SD = 128.02) relative to inhibit (M = 952, SD = 139.87) conditions ($F(1,15) = 9.064$, $p < .005$, $\eta p^2 = .377$). Of interest was a significant valence x task interaction ($F(1,15) = 36.831$, $p < .001$, $\eta p^2 = .711$) which was followed up with Bonferroni correction for adjusted alpha level (.05/2 tests was .025). Reaction times were faster in the select (M = 945.5, SD = 146.28) relative to inhibit (M = 1076.06, SD = 144.56) conditions for angry valence templates; $t(15) = -6.948$, $p < .001$, whereas reaction times were slower in the select (M = 882.75, SD = 109.76) relative to inhibit (M = 828.31, SD = 135.17) conditions for neutral valence templates; $t(15) = 2.622$, $p = .019$.

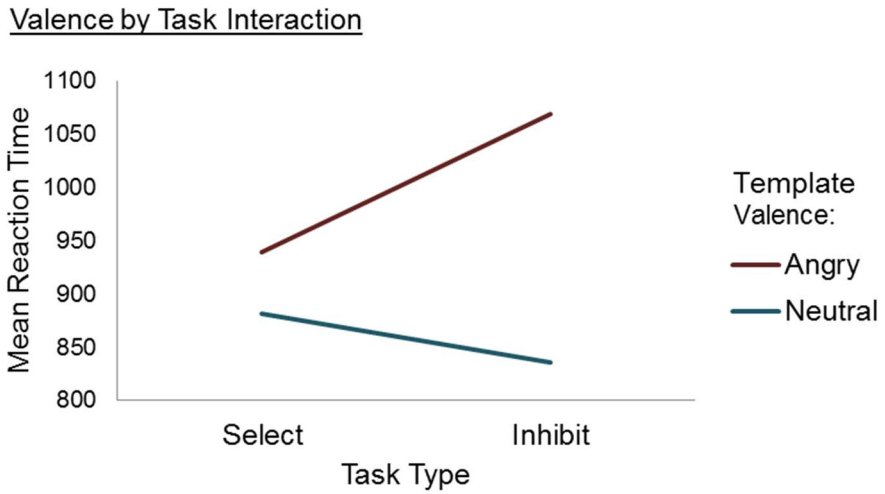


Figure 2.6 Line graph demonstrating faster reaction times in the select, relative to inhibit angry conditions, and slower reaction times in the select, relative to inhibit neutral conditions.

2.3.2: *Electroencephalography Results*

Only trials where target sex was correctly reported were included in the analysis and response times below 300ms were discarded. Where post-hoc t-tests were carried out, the Bonferroni correction for adjusted alpha level (.05/number of tests) was applied. Where Mauchley's test for the assumption of sphericity was violated, Greenhouse-Geisser corrected values were reported with degrees of freedom taken from sphericity assumed.

Figures 6 and 7 show ERPs observed at lateral parietal-occipital electrode sites PO7 and PO8, contralateral and ipsilateral to the location of angry face templates (figure 6) and neutral face templates (figure 7). Select versus inhibit templates are represented to the left and right, respectively. Contralateral wave-forms are depicted by dotted lines. Ipsilateral wave-forms are depicted by solid lines. Figures 8 and 9 show contralateral minus ipsilateral difference waves for angry (select (black line) vs. inhibit (red line)) and neutral (select (black line) vs. inhibit (blue line)) conditions.

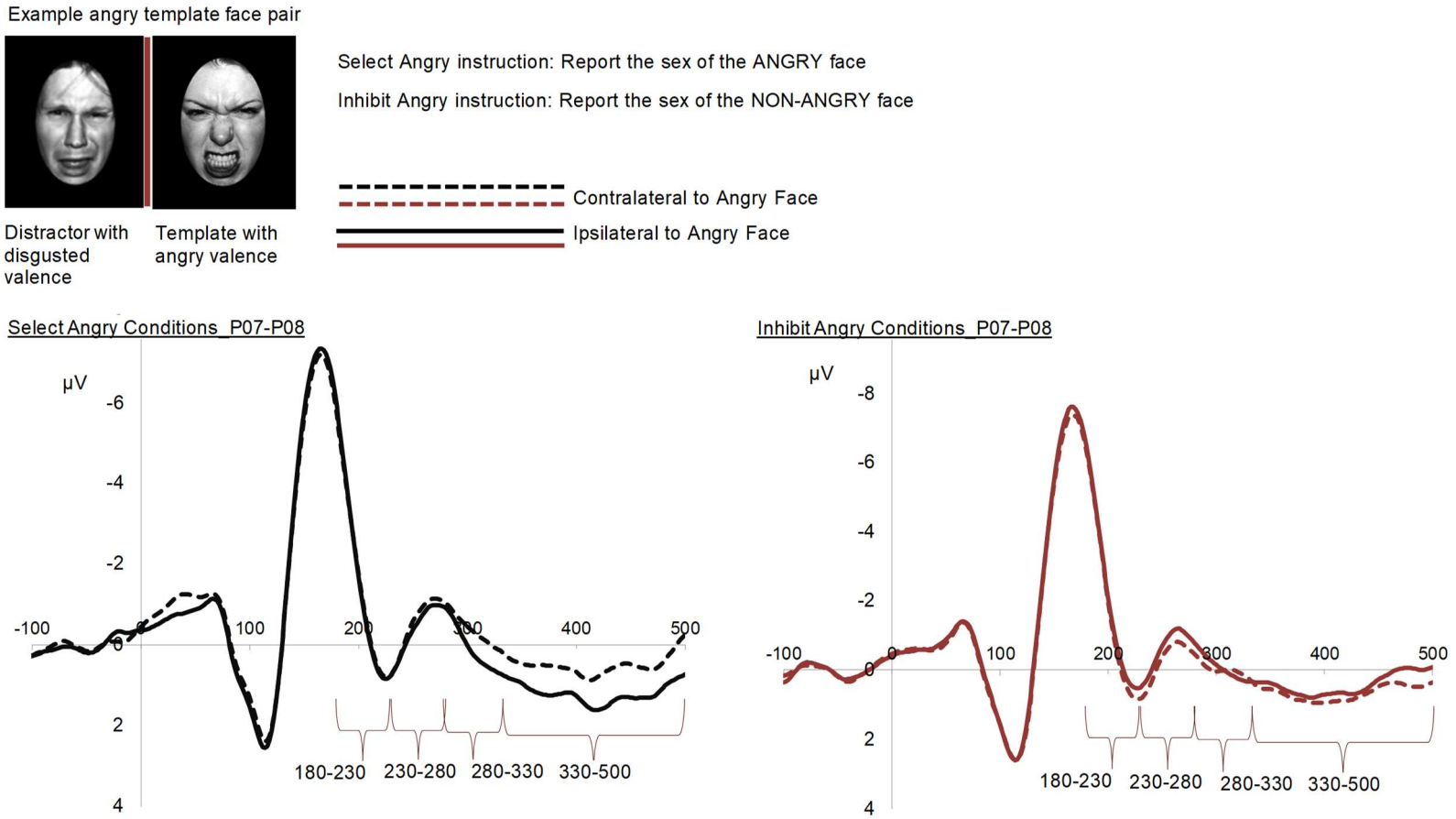


Figure 2.7 Grand averaged ERPs for electrodes PO7/PO8 contralateral and ipsilateral to angry templates-for-selection (left) and angry templates-for-rejection (right). Time windows 180-230, 230-280, 280-330 and 330-500 are depicted. Note that ERPs are plotted with negative voltage up. The select angry ERP wave-form demonstrates a negative deflection at contralateral relative to ipsilateral scalp sites, beginning approximately 260ms post-stimulus. The inhibit angry ERP wave-form demonstrates a positive deflection at contralateral relative to ipsilateral scalp sites, beginning approximately 215ms post-stimulus. Approximately 300ms post-stimulus, the contralateral wave-form switches to negative polarity, then resumes positive polarity at 335ms post-stimulus. Contralateral divergence visually began earlier in the inhibit, compared with the select angry condition.

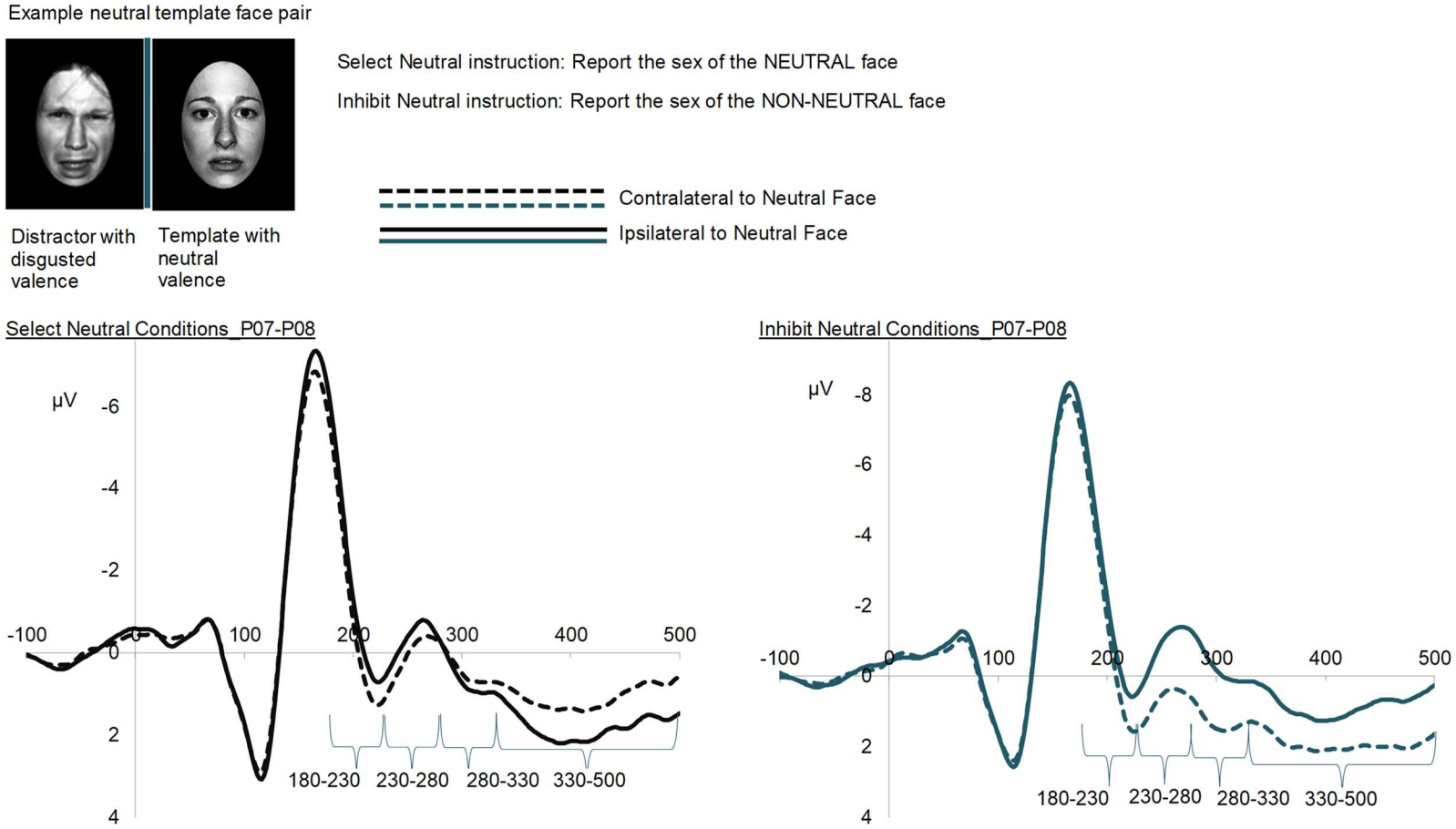


Figure 2.8 Grand averaged ERPs for electrodes PO7/PO8 contralateral and ipsilateral to neutral templates-for-selection (left) and neutral templates-for-rejection (right). Time windows 180-230, 230-280, 280-330 and 330-500 are depicted. Note that ERPs are plotted with negative voltage up. The select neutral ERP wave-form appears similar to the inhibit neutral condition, as contralateral divergence was *positive* rather than *negative*, and began approximately 215ms post-stimulus. The polarity of the contralateral wave-form switched to negative at approximately 285ms post-stimulus. The inhibit neutral condition depicts a contralateral positivity beginning approximately 215ms post-stimulus, which remains throughout the duration of the ERP wave-form.

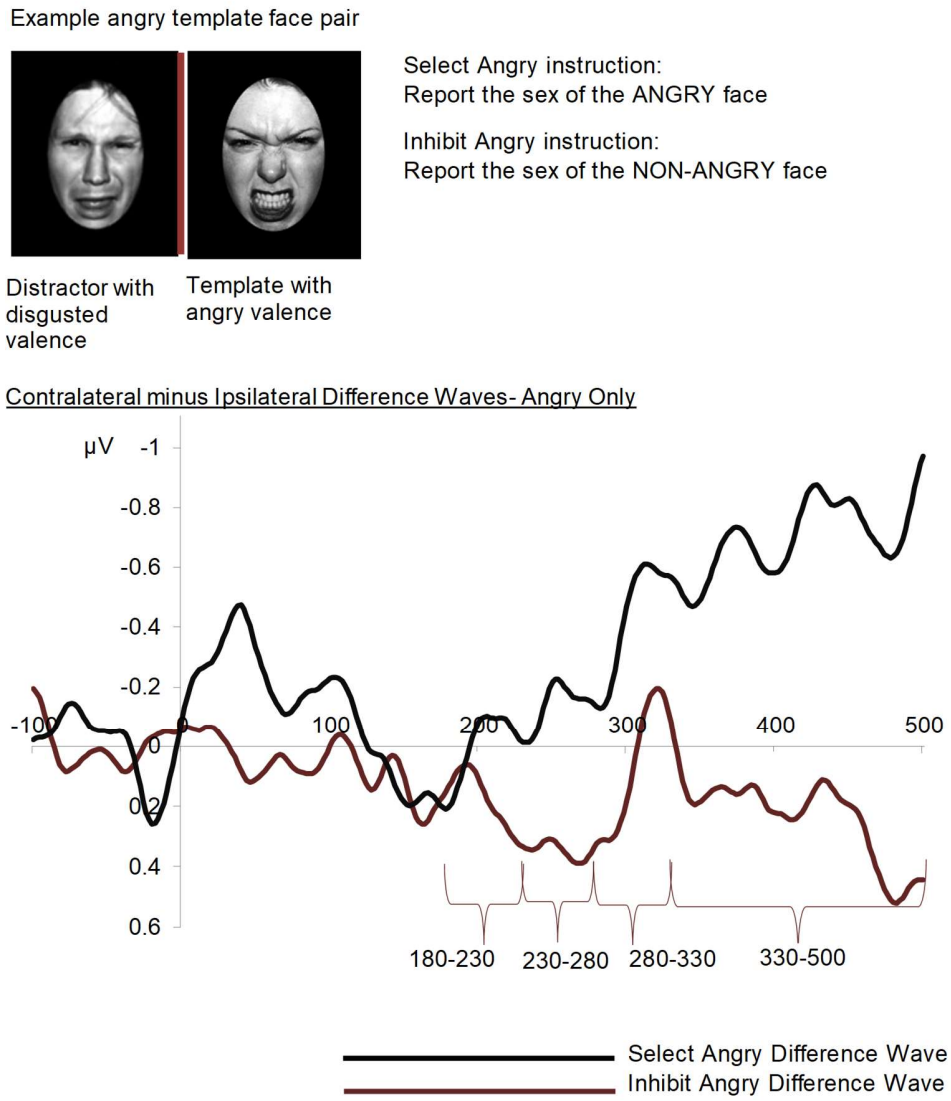


Figure 2.9 Contralateral minus ipsilateral difference waves for angry templates-for-selection (black line) and angry templates-for-rejection (red line). Time windows 180-230, 230-280, 280-330 and 330-500 are depicted.
Visually, there appears to be some contralateral divergence early on (prior to-100ms post-stimulus). Clearer divergence between select and inhibit angry conditions begins at approximately 200ms post-stimulus, where the wave-forms depict a contralateral negativity versus a contralateral positivity to select versus inhibit angry conditions, respectively.

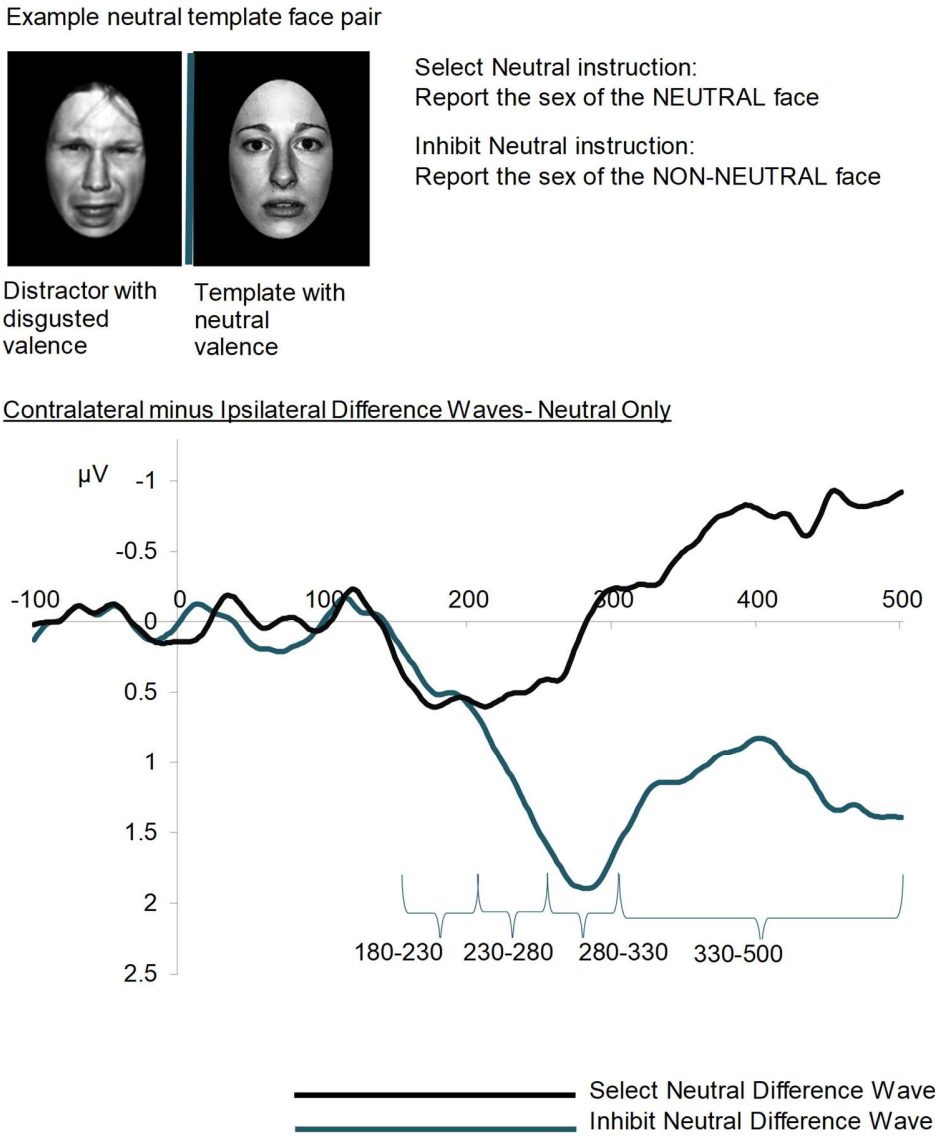


Figure 2.10 Contralateral minus ipsilateral difference waves for neutral templates-for-selection (black line) and neutral templates-for-rejection (blue line). Time windows 180-230, 230-280, 280-330 and 330-500 are depicted.
Contralateral divergence visually differs between the neutral conditions approximately 200ms post-stimulus, where greater contralateral difference can be seen for the inhibit compared to select neutral condition.

2.3.2.1: ***Statistical Analyses of ERPs- ANOVA: all conditions***

Mean ERP amplitudes were entered into a 2 x 2 x 2 x 4 repeated measures ANOVA with the factors: template valence (angry vs. neutral), task (select vs. inhibit), laterality (contralateral vs. ipsilateral to angry/neutral template), and component (180-230 ms, 230-280 ms, 280-330 ms, 330-500 ms). See experiment methods (*ERP Components*) for details regarding selected time-windows and functional interpretation.

A main effect of laterality ($F(1,15) = 4.836$, $p < .05$, $\eta p^2 = .244$) revealed that mean amplitudes were more positive at contralateral ($M = .01$ μV, $SEM = .61$) relative to ipsilateral ($M = -.27$ μV, $SEM = .66$) electrode locations. There was a main effect of component ($F(3,45) = 6.947$, $p = .001$, $\eta p^2 = .317$); where mean amplitudes during the 180-230 ms time window ($M = -1.46$ μV, $SEM = .75$) were more negative, compared to the 230-280 ms time window ($M = -.24$ μV, $SEM = .66$), then became increasingly positive over the 280-330 ms ($M = .21$ μV, $SEM = .72$) and 330-500 ms time windows ($M = .97$ μV, $SEM = .72$). It was further revealed that mean amplitudes were significantly more negative in response to angry ($M = -.38$ μV, SEM = .65) relative to neutral ($M = .12$ μV, $SEM = .63$) valence templates ($F(1,15) = 5.177$, $p < .05$, $\eta p^2 = .257$). There was no main effect of task ($F<1$); however interaction effects for task x laterality ($F(1,15) = 14.486$, $p < .005$, $\eta p^2 = .491$), and component x task ($F(3,45) = 6.121$, $p = .005$, $\eta p^2 = .290$) did reach significance, and were subsumed under a component x task x laterality 3-way interaction ($F(3,45) = 5.014$, $p < .005$, $\eta p^2 = .251$). A 2-way interaction for valence x laterality ($F(1,15) = 8.423$, $p < .05$, $\eta p^2 = .36$), and 3-way interaction for component x valence x laterality ($F(3,45) = 5.52$, $p < .005$, $\eta p^2 = .269$) were encompassed within a highly significant component x task x valence x laterality 4-way interaction ($F(3,45) = 9.304$, $p < .001$, $\eta p^2 = .383$), which has been deconstructed through subsequent ANOVAs.

2.3.2.1.1*: Deconstruction of 4-way Interaction using Difference Scores*

To deconstruct the 4-way interaction, laterality effects were operationalised as difference scores by subtracting the mean amplitude ipsilateral to angry/neutral templates from the mean amplitude contralateral to angry/neutral templates, calculated for each ERP component, according to valence and task. For the purpose of deconstructing the four-way interaction, separate 2 x 4 repeated measures ANOVAs were computed for the angry valence and neutral valence conditions.

2.3.2.1.1.1: *Angry Valence Templates*

Within angry valence, there was no significant main effect of component ($F(3,45) = .561$, ns, $\eta p^2 = .036$), or task ($F(1,15) = 1.772$, $p > .05$, $\eta p^2 = .106$), and the component x task interaction was non-significant ($F(3,45) = .662$, $p > .05$, $\eta p^2 = .042$).

2.3.2.1.1.2: *Neutral Valence Templates*

Within neutral valence, there was a significant main effect of component ($F(3,45) = 7.692$, $p < .005$, $\eta p^2 = .339$), revealing a smaller laterality difference during the 180-230 ms (*MD* = .64 *μ*V, *SEM* = .12) compared to the 230-280 ms time window (*MD* = .97 *μ*V, *SEM* = .21), which became smaller again during the 280-330 ms (*MD* = .68 *μ*V, *SEM* = .15) and 330-500 ms time windows (*MD* = .19 *μ*V, *SEM* = .13). A significant main effect of task ($F(1,15) = 36.756$, $p < .001$, $\eta p^2 = .71$) was consistent with a greater laterality difference for inhibit (*MD* = 1.24 *μ*V, *SEM* = .2) compared to select (*MD* = .01 *μ*V, *SEM* = .09) neutral conditions. Also uncovered, was a highly significant component x task interaction ($F(3,45) = 17.139$, $p < .001$, $\eta p^2 = .533$). To deconstruct the interaction, one-way ANOVAs were computed separately for select neutral and inhibit neutral conditions, on the factor component.

2.3.2.1.1.2.1: Neutral templates-for-selection

There was a highly significant main effect of component ($F(3,45) = 20.29$, $p < .001$, $\eta p^2 = .575$), where the contralateral relativity diverged more within the 180-230 ms time-window (*M* = .56 *μ*V, *SEM* = .16) than within the 230-280 ms time-window (*M* = .38 *μ*V, *SEM* = .17), then diverged less and changed polarity within the 280-330 ms time-window (*M* = -.19 *μ*V, *SEM* = .12), becoming more enhanced during the 330-500 ms time-window (*M* = -.71, *SEM* = .11). Planned difference contrasts

with Bonferroni correction for multiple testing (.05/3 resulted in a significance threshold of p<.016) were carried out to investigate laterality differences for each time window, compared with its preceding time-window.

Difference scores were positive during the 230-280 ms (*MD* = .38 *μ*V, *SD* = .68) then negative during the 280-330 ms time-window (*MD* = -.19 *μ*V, *SD* = .46), ($F(1,15) = 20.96$, $p < .001$, $\eta p^2 = .583$); the effect is consistent with Figure 7 (ERP wave-form to select neutral) which depicts a N2pc flip between the 230-280 ms and 280-330 ms time windows, respectively. Difference scores reflected a significantly more pronounced contralateral relative negativity during the 330-500 ms (*MD* = -.72 *μ*V, *SEM* = .11) compared with the 280-330 ms (*MD* = *-.19 μ*V, *SEM* = .12) time-window; $F(1,15) = 22.836$, $p < .001$, $\eta p^2 = .604$. No other difference contrasts reached significance, all $p \geq .016$.

A contralateral positivity was present within the earlier time windows, which then switched to a contralateral negativity at 280-330 ms, showing an enhanced effect from 330-500 ms; this may reflect an initial pull of attention by emotional face distractors before attention was allocated towards the target neutral face. Attention was then sustained on the neutral face until the end of the recording interval at 500 ms.

2.3.2.1.1.2.2: Neutral templates-for-rejection

There was a highly significant main effect of component ($F(3,45) = 6.1$, $p = .001$, $\eta p^2 = .289$) where the contralateral relativity diverged less within the 180-230 ms time-window (*M* = .71 *μ*V, *SEM* = .17), compared to the 230-280 ms time-window (*M* = 1.56 *μ*V, *SEM* = .29), and remained comparable over the proceeding 280-330 ms time-window (*M* = 1.56 *μ*V, *SEM* = .28), then reduced during the 330-500 ms time-window (*M* = 1.12 *μ*V, *SEM* = .25).

Planned difference contrasts with Bonferroni adjusted alpha .016 per test (.05/3) were carried out to investigate laterality differences for each time window, compared with its preceding time-window. It was revealed that during the 230-280 ms time-window, contralateral relativity divergence was significantly more pronounced (*MD* = 1.56 *μ*V, *SEM* = .29) compared with the previous 180-230 ms

time-window (*MD* = .71 μV, *SEM* = .17); ($F(1,15) = 26.14$, $p < .001$, $\eta p^2 = .635$). No other difference contrasts reached significance, all $p \geq .016$.

The contralateral positivity was enhanced between the early (180-230 ms) to mid (230-280 ms/280-330 ms) time-windows, and was sustained, although with a reduced laterality difference (not statistically significant $F<1$) until the end of the recording interval at 500ms, consistent with active inhibition of neutral face templates.

2.3.2.1.2: *Component Analyses*

In order to investigate fully the study hypotheses, Analyses of Variance were performed on each separate component. Mean ERP amplitudes were entered into a 2 x 2 x 2 repeated measures ANOVA with the factors: template valence (angry vs. neutral), task (select vs. inhibit) and laterality (contralateral vs. ipsilateral to angry/neutral template).

2.3.2.1.2.1: 180-230 ms:

A main effect of laterality ($F(1,15) = 5.239$, $p < .05$, $\eta p^2 = .259$) revealed that mean amplitudes were less negative contralateral (*M* = -1.32 μV, *SEM* = .76) relative to ipsilateral (*M* = -1.59 μV, *SEM* = .75) to templates. There was a significant valence x laterality interaction ($F(1,15) = 10.084$, $p < .01$, $\eta p^2 = .402$), which was followed up with a Bonferroni correction of .025 (.05/2). It was revealed that mean amplitudes contralateral (*M* = -1.02 μV, *SD* = 2.89) relative to ipsilateral (*M* = -1.66 μV, *SD* = 3.01) to neutral templates were more positive ($t(15) = 5.191$, $p < .001$), compared with mean amplitudes contralateral (*M* = -1.62 μV, *SD* = 3.33) relative to ipsilateral (*M* = -1.52 μV, *SD* = 3.16) to angry templates ($t(15) = -.545$, *p* = ns). No other main effects or interactions reached significance, all $F \leq 1$, $p \geq .05$.

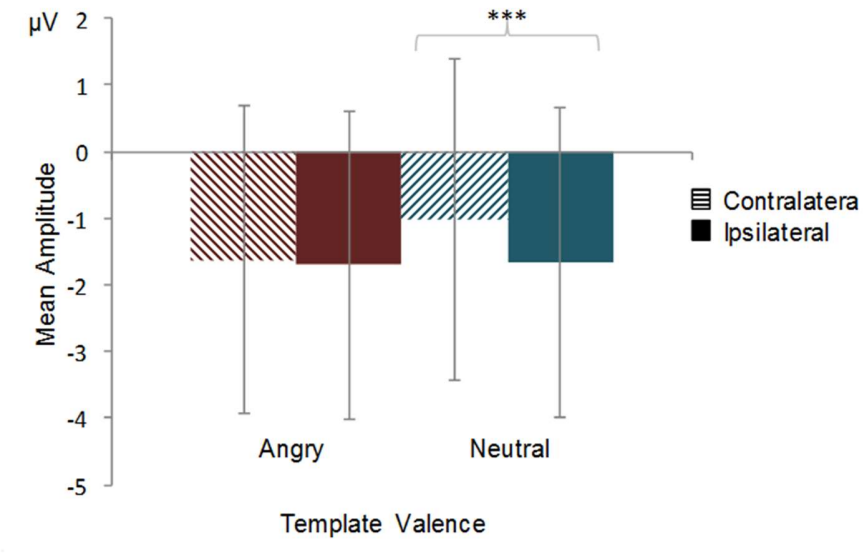


Figure 2.11 Graph demonstrates valence x laterality interaction. Diagonal lines versus solid colour depict contralateral versus ipsilateral, respectively. Downward versus upward sloping diagonal lines depict relative negativity versus relative positivity, respectively. Error bars represent the standard deviation for each condition: angry- contralateral/ipsilateral, compared with neutral- contralateral/ipsilateral. Significance level is indicated above the brace. There was a relative positivity in response to neutral valence, which was not present in response to angry valence.

2.3.2.1.2.2: 230-280 ms

A significant main effect of laterality ($F(1,15) = 6.55$, $p < .05$, $\eta p^2 = .304$) revealed that mean amplitudes were more positive contralateral ($M = -.01$ μV, $SEM = .62$) relative to ipsilateral ($M = -.47$ μV, $SEM = .72$) to templates. A significant task x laterality interaction ($F(1,15) = 14.426$, $p < .005$, $\eta p^2 = .49$) was followed up with Bonferroni adjusted alpha .025 per test (.05/2). In line with the inhibition of angry/neutral template faces there were comparable mean amplitudes contralateral ($M = -.23$ μV, $SD = 2.53$) and ipsilateral ($M = -.21$ μV, $SD = 2.74$) to select templates ($t(15) = -.095$, p = ns), compared with significantly more positive mean amplitudes contralateral ($M = .22$ μV, $SD = 2.46$) relative to ipsilateral ($M = -.73$ μV, $SD = 3.05$) to inhibit templates ($t(15) = 4.959$, $p < .001$). Also revealed, was a significant valence x laterality interaction ($F(1,15) = 10.95$, $p = .005$, $\eta p^2 = .422$); mean amplitudes were significantly more positive contralateral ($M = .38$ μV, $SD = 2.61$) relative to ipsilateral ($M = -.59$ μV, $SD = 3.04$) to neutral templates ($t(15) = 4.739$, $p < .001$), but did not significantly differ contralateral ($M = -.39$ μV, $SD = 2.53$) relative to ipsilateral ($M = -.35$ μV, $SD = 2.78$) to angry templates ($t(15) = -.159$, $p =$

ns) (Bonferroni adjusted alpha was .025 per test (.05/2)). No other main effects or interactions reached significance, all $F \leq 1$, $p \geq .05$.

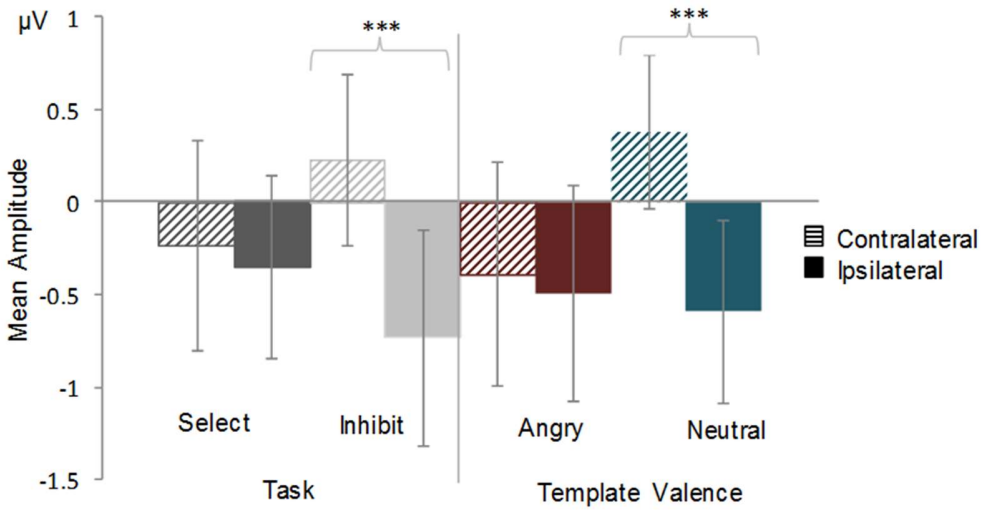


Figure 2.12 Graph demonstrates task x laterality interaction (left) and valence x laterality interaction (right). Diagonal lines versus solid colour depict contralateral versus ipsilateral, respectively. Downward versus upward sloping diagonal lines depict relative negativity versus relative positivity, respectively. Error bars represent the standard deviation for each condition: select- contralateral/ipsilateral, compared with inhibit- contralateral/ipsilateral (left), and angry- contralateral/ipsilateral, compared with neutral- contralateral/ipsilateral (right). Significance level is indicated above the braces.
Left- There was a relative positivity in response to inhibit templates, whereas there was no significant contralateral relativity in response select templates.
Right- There was a relative positivity in response to neutral templates, whereas there was no significant contralateral relativity in response to angry templates.

2.3.2.1.2.3: 280-330 ms

A main effect of valence ($F(1,15) = 9.207$, $p < .01$, $\eta p^2 = .38$) demonstrated that mean amplitudes in response to neutral templates ($M = .55$ μV, $SEM = .71$) were more positive than in response to angry templates ($M = -.12$ μV, $SEM = .75$). Significant 2-way interactions for valence x laterality ($F(1,15) = 7.211$, $p = .017$, $\eta p^2 = .325$) and task x laterality ($F(1,15) = 15.786$, $p < .001$, $\eta p^2 = .513$), were subsumed under a 3-way valence x task x laterality interaction ($F(1,15) = 7.025$, $p = .018$, $\eta p^2 = .319$). To deconstruct the 3-way interaction, separate 2-way ANOVAs were run for angry and neutral templates, on the factors laterality and task. No other main effects or interactions reached significance, all $p \geq .05$.

2.3.2.1.2.3.1: Angry Templates (280-330 ms):

There was no main effect of laterality ($F(1,15) = .271$, ns, $\eta p^2 = .018$), or task ($F(1,15) = .239$, ns, $\eta p^2 = .016$), and the task by laterality interaction was non-significant ($F(1,15) = .997$, ns, $\eta p^2 = .062$).

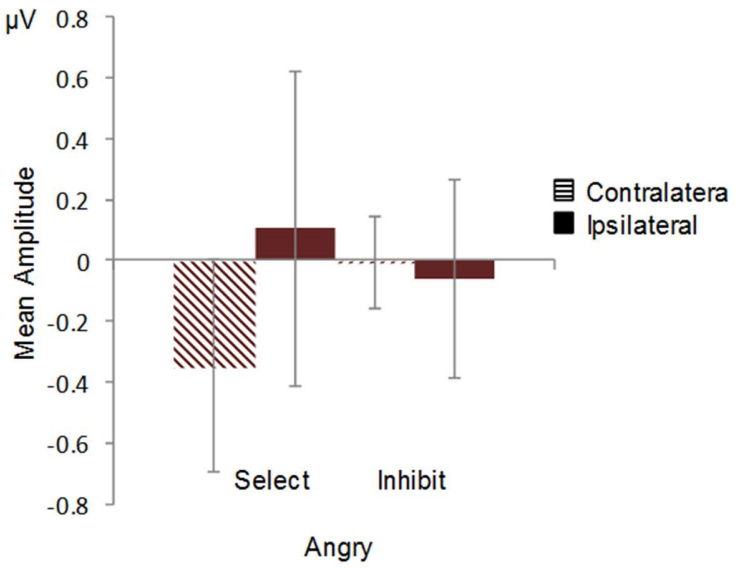


Figure 2.13 Graph demonstrates mean amplitudes in response to angry templates- select/inhibit. Diagonal lines versus solid colour depict contralateral versus ipsilateral, respectively. Downward versus upward sloping diagonal lines depict relative negativity versus relative positivity, respectively. Error bars represent the standard deviation for each condition.
Neither the relative negativity to select angry (left), nor the relative positivity to inhibit angry (right) approached significance.

2.3.2.1.2.3.2: Neutral Templates (280-330 ms):

A highly significant main effect of laterality ($F(1,15) = 20.487$, $p < .001$, $\eta p^2 = .577$) confirmed more positive mean amplitudes contralateral to neutral templates ($M = .89$ μV, $SEM = .67$), relative to ipsilateral ($M = .21$ μV, $SEM = .75$). A highly significant task x laterality interaction ($F(1,15) = 34.049$, $p < .001$, $\eta p^2 = .694$) was deconstructed through post-hoc t-tests with Bonferroni adjusted alpha .025 per test (.05/2). Mean amplitudes contralateral to inhibit neutral templates ($M = 1.33$ μV, $SD = 2.59$) were significantly more positive than ipsilateral ($M = -.23$ μV, $SD = 3.18$), ($t(15) = 5.611$, $p < .001$), consistent with active inhibition of neutral face templates. Although the direction of mean amplitudes contralateral ($M = .45$ μV, $SD = 2.85$) relative to ipsilateral ($M = .65$ μV, $SD = 2.98$) to select neutral templates demonstrated a negativity, the difference did not approach significance ($t(15) = -1.699$, $p > .025$). No other main effects or interactions reached significance, all $F \leq 1$, $p \geq .05$.

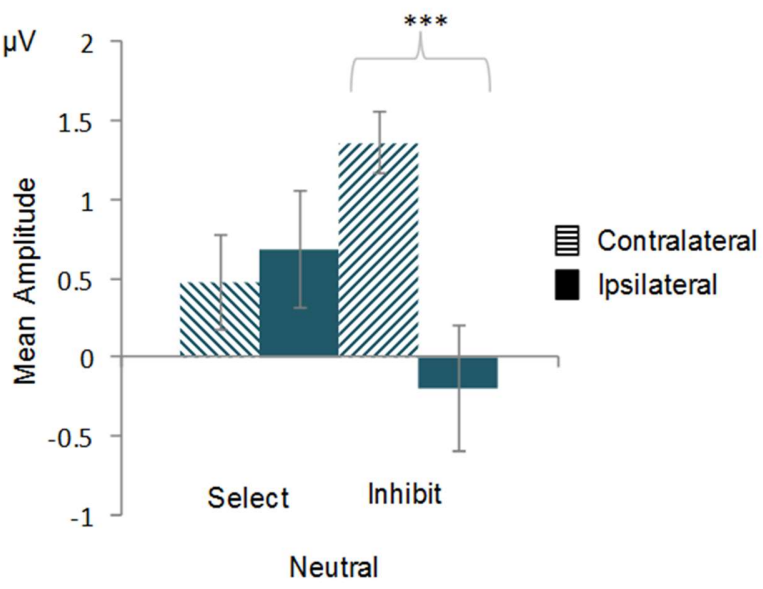


Figure 2.14 Graph demonstrates mean amplitudes in response to neutral templates- select/inhibit. Diagonal lines versus solid colour depict contralateral versus ipsilateral, respectively. Downward versus upward sloping diagonal lines depict relative negativity versus relative positivity, respectively. Error bars represent the standard deviation for each condition. Significance level is indicated above the braces.
The relative negativity in response to select neutral templates (left) did not reach significance, whereas the relative positivity in response to inhibit neutral templates (right) was highly significant.

2.3.2.1.2.4: 330-500 ms:

There was a main effect of valence ($F(1,15) = 17.141$, $p = .001$, $\eta p^2 = .533$), where mean amplitudes were more positive in response to neutral templates ($M = 1.39$ μV, $SEM = .73$), compared to angry templates ($M = .54$ μV, $SEM = .74$). A significant task x laterality interaction ($F(1,15) = 16.544$, $p = .001$, $\eta p^2 = .524$) was subsumed under a highly significant 3-way valence x task x laterality interaction ($F(1,15) = 26.07$, $p < .001$, $\eta p^2 = .635$). To deconstruct the 3-way interaction, separate 2-way ANOVAs were run for angry and neutral templates, on the factors laterality and task. No other main effects or interactions reached significance, all $p \geq .05$.

2.3.2.1.2.4.1: Angry Templates (330-500 ms):

There was no main effect of laterality ($F(1,15) = .110$, ns, $\eta p^2 = .007$), or task ($F(1,15) = .005$, ns, $\eta p^2 = .0$), and the task x laterality interaction was non-significant ($F(1,15) = 1.02$, $p > .05$, $\eta p^2 = .064$).

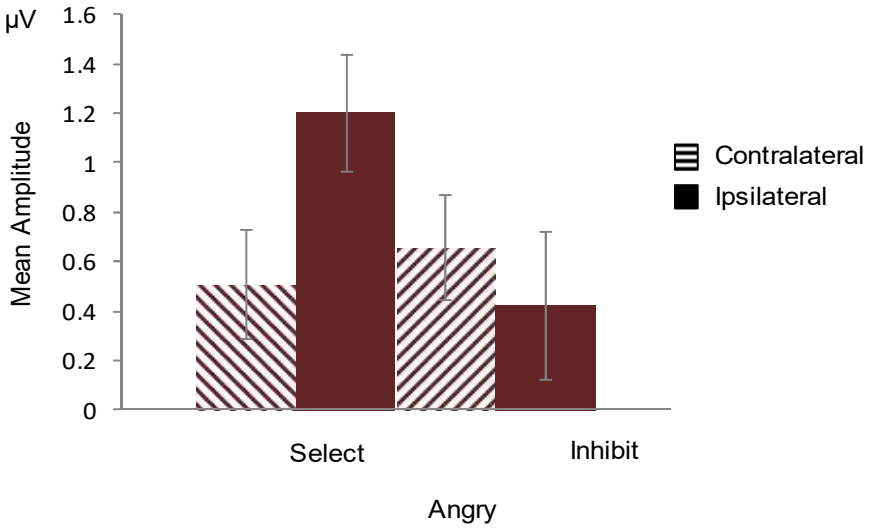


Figure 2.15 Graph demonstrates mean amplitudes in response to angry templates- select/inhibit. Diagonal lines versus solid colour depict contralateral versus ipsilateral, respectively. Downward versus upward sloping diagonal lines depict relative negativity versus relative positivity, respectively. Error bars represent the standard deviation for each condition.
Neither the relative negativity to select angry (left), nor the relative positivity to inhibit angry (right), approached significance.

2.3.2.1.2.4.2: Neutral Templates (330-500 ms):

There was a highly significant task x laterality interaction ($F(1,15) = 42.771$, $p < .001$, $\eta p^2 = .74$). Post-hoc t-tests with Bonferroni adjusted alpha .025 per test (.05/2) were performed to follow up the significant interaction. In response to select neutral templates, mean amplitudes were significantly less positive contralateral ($M = 1.06$ μV, $SD = 3.01$) relative to ipsilateral ($M = 1.78$ μV, $SD = 3.07$), ($t(15) = -6.543$, $p < .001$), consistent with attentional selection of, and sustained attention towards, neutral target templates. In response to inhibit neutral templates, mean amplitudes were significantly more positive contralateral ($M = 1.9$ μV, $SD = 2.78$) relative to ipsilateral (M = .79 μV, SD = 3.04); $t(15) = 4.551$, $p < .001$, consistent with active inhibition of neutral templates. No other main effects or interactions reached significance, all $p \geq .05$.

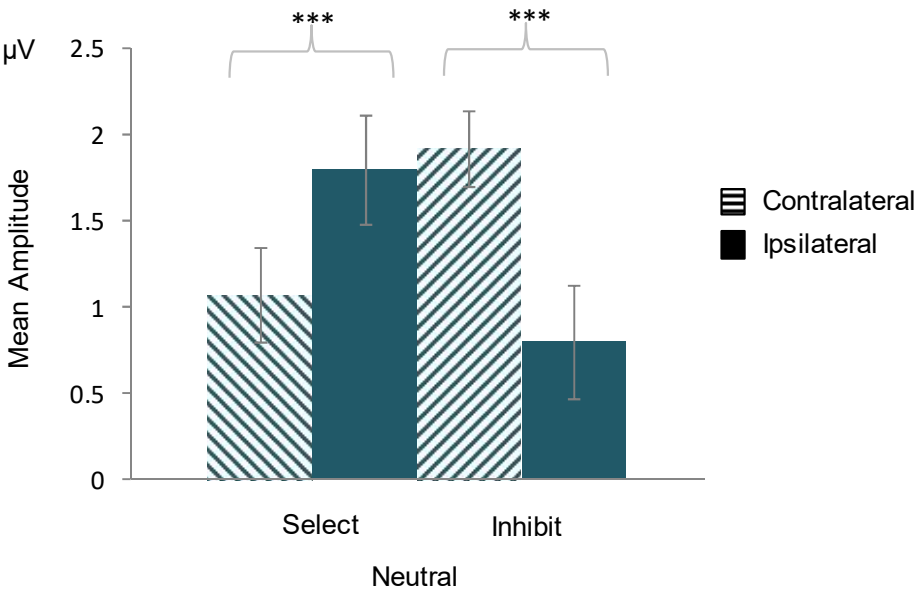


Figure 2.16 Graph demonstrates mean amplitudes in response to neutral templates- select/inhibit. Diagonal lines versus solid colour depict contralateral versus ipsilateral, respectively. Downward versus upward sloping diagonal lines depict relative negativity versus relative positivity, respectively. Error bars represent the standard deviation for each condition. Significance level is indicated above the braces.
The significant relative negativity to select neutral templates (left), differed to the significant relative positivity to inhibit neutral templates (right).

2.4: Discussion

The first experiment aimed to investigate: 1) What the impact of emotionally salient distractor stimuli would be when angry, versus neutral valence is utilised as a t-f-s. An N2pc, followed directly by a P_D to template-matching targets was expected to indicate attentional selection, followed by active termination of attentional selection to template-matching targets (see Sawaki et al., 2012). Alternatively, an N2pc that gradually attenuates was expected to indicate that template-matching targets were allocated enhanced processing resources, encouraging maintenance of attentional selection to template-matching to the target stimulus (see Bundeson, 1990; Bundeson et al., 2005); 2) What the impact of emotionally salient target stimuli would be when angry, versus neutral valence is utilised as a t-f-r. A P_D contralateral to template-matching distractors was expected to be in line with Sawaki and Luck's (2010) SSH, demonstrating active suppression of the "attend-to-me" priority signal elicited by template-matching distractors. Alternatively, an 'N2pc flip' (term used by Jannati et al., 2013; Liesefeld et al., 2017; McDonald et al., 2013; Woodman & Luck, 1999) that is first contralateral to template-matching distractor, then contralateral to emotional valence targets was expected to be in-line with post-capture neural dynamics reported by Liesefeld et al. (2017), demonstrating that stimuli with template-matching distractor features initially capture attention before the attentional capture response is actively suppressed and attention redeployed to the target.

The behavioural data found lower overall accuracy and slower reaction times (RTs) in response to the angry template conditions, compared with the neutral template conditions, demonstrating that the emotional salience of angry, compared with neutral valence, impaired task performance, possibly because exogenous prioritisation of emotion slowed endogenous task-driven processing. This was most likely influenced by increased competition for processing resources when both (angry blocks), rather than only one (neutral blocks) stimulus on the array had high emotional salience.

It was also revealed that RTs were faster when angry valence was a t-f-s, compared to a t-f-r, suggesting that when pairs of emotionally salient stimuli (angry paired with happy, sad, surprise, or

disgust) compete for processing prioritisation (see Desimone & Duncan, 1995), angry t-f-s preferentially biased the competition for attentional resources so that they received processing prioritisation. Conversely, when angry valence was a t-f-r, processing prioritisation of the angry face appeared to impair, rather than enhance the cognitive control mechanisms necessary for template guided inhibition. The finding supports previous studies that showed an attentional bias for threat over other facial expressions (e.g. Eastwood et al., 2003; Eastwood et al., 2001; Holmes et al., 2014).

It was expected that the ERP response profile to angry valence t-f-s and angry valence t-f-r, would help to elucidate neuro-mechanistic function associated with the pattern of behavioural effects that were observed.

There were no significant ERP effects within the angry valence conditions. The absence of significant ERP findings in the angry valence conditions may be grounded in the unique aspect of the angry valence paradigm set up, wherein target and distractor stimuli were both emotionally salient. Batty and Taylor (2003) reported automatic, rapid processing of the six basic emotions (happy, angry, sad, surprise, disgust and fear) and Holmes et al. (2009) report an enhanced N2pc to both angry and happy face stimuli when they appeared beside neutral face stimuli; notably, Holmes et al. (2009) found that the amplitude of the N2pc to angry compared to happy face stimuli did not statistically differ, however angry face stimuli elicited an earlier N2pc than did happy face stimuli. Taken together, the findings suggest that emotional salience, whether it be angry, happy, sad, surprise, fear, or disgust, appears to elicit an “attend to me” priority signal (see Sawaki & Luck, 2010). Crucially, when pairs of emotionally salient stimuli both elicit “attend-to-me” priority signals, competition for processing resources (see Desimone & Duncan, 1995) may evoke a loggerhead response, so that neither stimulus received statistically identifiable attentional focus.

Accuracy was equal irrespective of whether the neutral face was a t-f-r, or a t-f-s. In contrast, faster responses were recorded on the neutral t-f-r, versus selection block. The behavioural findings appear to support that participants were more successful at utilising neutral facial valence as a t-f-r, than selection. This finding contrasts to what would be expected if the experiment had used colour

singletons; for example, Arita et al. (2012) found that participants located a search target faster when a cue at the start of each trial indicated the colour of the target (template-for-selection), as compared with the distractor (template-for-rejection). Thus, the current experiment results appear to be in the opposite direction to what would logically be expected. However, neutral facial valence in the current experiment was less salient than the face that it appeared opposite to. This would presumably have meant that more attentional control was required to select the neutral face than the emotional face. By examining the ERP findings, it will be possible to clarify the underpinnings of these effects.

The ERP data for the neutral t-f-s block depicted a profile of response that supported initial attentional capture by the emotional distractor face, as an N2pc (contralateral negativity) was evoked contralateral to the emotional face. An N2pc flip followed so that a contralateral negativity then emerged contralateral to the neutral face. The N2pc flip likely reflected the sum of an endogenous shift of attention to the neutral face on the opposite side of the screen, combined with active suppression of attentional capture by the emotional distractor face. Although the bilateral design used in experiment one could not clarify for certain if the observed N2pc flip was underpinned by the sequence of processing suggested, the findings of two previous studies do support the interpretation suggested here.

Woodman and Luck (1999, 2003) revealed that search for multiple target stimuli elicited consecutive N2pc components i.e. an initial target-one N2pc opposite to the left visual field target, was followed by an N2pc flip, reflecting a second target-two N2pc opposite to the right visual field target from approx. 300ms post stimulus onset. The latency of the second N2pc was similar to that observed for the current experiment one in which laterality divergence after the N2pc flip became significant from 330ms post stimulus onset. It is currently suggested that in the neutral t-f-s condition, the N2pc flip indexed not only a shift of attention to the neutral face, but also attentional suppression of early attentional capture by the emotional face. Indeed, it is possible that the slightly later onset of laterality divergence here (330ms) may reflect this additional process. Indeed, Liesefeld et al. (2017) reported an N2pc flip that reflected initial attentional capture, followed by the sum of endogenous redeployment of attention towards the less salient target and active suppression of the initial attentional capture

response, and similar to the current findings, laterality divergence for the flipped N2pc became significant from approx. 330ms post stimulus onset. Liesefeld et al. (2017) were able to support that the N2pc flip they observed was underpinned by the sum of attentional capture suppression and attentional redeployment because the authors included an additional array in which the lateralised ERP could be isolated with respect to which stimulus it had been triggered by (lateral target with midline distractor, and lateral distractor with midline target). Because experiment one used only a bilateral display, the suggested explanation for the profile of N2pc response could not be clarified.

The ERP data for the neutral t-f-r block revealed a P_D component contralateral to the neutral t-f-r. This was initially interpreted as evidence for early active suppression of the stimulus that matched the neutral t-f-r. However, as the opposite sided emotional face was more salient than the neutral face, what looked like attentional suppression of the neutral face may instead have been attentional capture by the emotional face. Specifically, because faces appeared bilaterally on the array, a P_D component contralateral to the neutral face would look the same as an N2pc component contralateral to the emotional face. However, it is also possible that the ERP response observed on the neutral t-f-r block reflected the sum of neutral distractor face suppression (P_D contralateral the t-f-r matching neutral face) and emotional face selection (N2pc contralateral to the emotional face target).

The proposed interpretations for the findings of experiment one could not be clarified with certainty because stimuli only appeared on bilateral search displays. Subsequent experiments will employ search arrays in which it will be possible to isolate the lateralised ERP component response to the evoking stimulus. To do this, one stimulus will be laterally presented and the other vertically presented. The use of Hickey et al. (2009) style search displays will clarify whether the interpretations suggested in the current discussion do indeed explain the pattern of effects observed. Thus, if the behavioural findings for the current experiment are replicated when the same stimuli appear on Hickey et al. (2009) style search displays then the attentional underpinnings responsible will be revealed.

Chapter 3: Neutral templates-for-rejection and selection

3.1: Introduction

The previous experiment of the thesis revealed faster reaction times when neutral faces were t-f-r, compared to t-f-s. Also shown was a contralateral positivity to neutral t-f-r that continued throughout the ERP profile, indicating sustained inhibition. Initially, it was proposed that participants successfully utilised neutral valence as a template-for-rejection; however, ignoring the neutral face on template-for-rejection trials would look the same as attentional selection of the adjacently presented emotional face. Because of the bilateral nature of the search array, a large contralateral negativity to (attentional selection of) the concurrently presented emotional face would look the same as a contralateral positivity to (inhibition of) the neutral t-f-r. Indeed, previous research (e.g., Eastwood et al., 2003; Holmes et al., 2014) showed that emotional, compared with neutral stimuli evoked enhanced N2pc contralaterality.

The experiment one findings could not confirm that attention was pulled in a stimulus-driven manner by the most salient (emotional) face; however, previous work has demonstrated that facial emotion receives special processing status (see Calvo, Nummenmaa, & Avaro, 2010; Csathó et al., 2008; Eastwood et al., 2001; Fenske, & Eastwood, 2003; Fox et al., 2001; Fox et al., 2002; Gosselin & Simard, 1999; Holmes et al., 2009; Lassalle & Itier, 2013; Ohman et al., 2001; Tomkins, 1962; Tottenham, Tanaka, Leon, McCarry, Nurse, Hare et al., 2009; Vuilleumier & Schwartz, 2001a, 2001b). For example, facial expressions that cue or depict potential threat have been shown to capture and hold attentional focus (e.g., Fox et al., 2001; Fox et al., 2002); whereas happy valence has been suggested to benefit from enhanced processing due to its associated value with reward, initiation and maintenance of social interactions and positive bonds (e.g., Calvo et al., 2010; Tomkins, 1962).

Evidence even exists of distinct neural systems responsible for processing specific facial emotions; for example, facial expressions of fear may be specifically processed by the amygdala (Pourtois et al., 2013); whereas processing facial expressions of disgust have been linked to the insula and basal ganglia (see Adolphs, 2002).

With respect to the aforementioned ambiguity surrounding bilateral stimulus use in experiment one, a novel paradigm designed by Hickey et al. (2009) was adapted for use in the current experiment two. Hickey et al. (2009) were able to isolate which stimulus was responsible for the attention response observed in their data because they presented only one stimulus at lateral location, with the other stimulus on the vertical midline. Based on knowledge that the attention related N2pc is a lateralised component, Hickey et al. (2009) were able to confirm with a high level of certainty, that the ERP responses they observed were elicited by the isolated lateral stimulus. Through use of this sparse display paradigm Hickey et al. (2009) revealed that a P_D (contralateral positivity), versus N_T (contralateral negativity) were respectively evoked by the lateral distractor versus target stimulus and that the classical N2pc reflects the sum of these components.

Recently, Bretherton et al. (2017) also employed a sparse search array analogous to that used by Hickey et al. (2009). Participants were tasked to discriminate the shape of a target stimulus (square or diamond) whilst ignoring either a scrambled, or intact face. A P_D response (indicating suppression), was evoked by laterally presented distractors during the 180-250 ms interval. Notably though, prior to P_D indexed attentional suppression, a distractor elicited negativity (indicating attentional selection) was observed during the earlier 120-180 ms interval; this early response emerged to the intact face only. The findings suggest that stimuli which have socio-motivational relevance may not be directly suppressed, but may instead evoke initial attentional capture which confers the findings of studies showing special attentional prioritisation of faces (e.g., Eastwood et al., 2001; Fenske, & Eastwood, 2003; Fox et al., 2001; Fox et al., 2002; Holmes et al., 2009; Ohman et al., 2001; Vuilleumier & Schwartz, 2001a, 2001b).

Bretherton et al. (2017) further revealed that when perceptual load was low, valence of the intact face (angry vs. neutral) did not differentially modulate early N_D or subsequent P_D component laterality. However, when perceptual load was high, early N_D (130-170 ms) laterality divergence was significant in response to angry, but not neutral valence. The data suggest that social cues depicting threat evoke automatic stimulus-driven processing irrespective of perceptual load. Neutral social cues do not appear to evoke the same level of processing prioritisation; instead, they appear to incur early selection prior to suppression only when current perceptual demands are low. Notably, Bretherton et al. (2017) found that behavioural performance was unaffected by distractor valence, a finding which

demonstrates the capability of the ERP technique in addition to behavioural measures, to elucidate neurocognitive mechanisms that underlie humans ability to maintain consistent task performance. It is likely that the early selection of (N_D response to) the angry valence distractor played a role in the observed consistency of task performance between the angry and neutral valence conditions reported by Bretherton et al. (2017).

In a recent review by Gaspelin and Luck (2019) the terms *proactive suppression* and *reactive suppression* were used to extend Sawaki and Luck's (2010) Signal Suppression Hypothesis 'of attentional capture' (SSH). The original SSH was proposed by Sawaki and Luck (2010) to explain their finding that in response to rapid serial search of a cued region, a salient distractor for which colour could be predicted, evoked a P_D (attentional suppression) response during early (100ms post-stimulus onset) attention processing. The authors proposed that the colour feature of the salient distractor elicited an early attend-to-me priority signal that was actively suppressed to prevent attentional capture by the salient, but task-irrelevant feature-matching item. Subsequent investigations reported contrasting evidence with respect to whether or not distractors can be actively suppressed prior to being selected. For example, Cunningham and Egeth (2016) and Moher and Egeth (2012) reported slower target identification speed when a cue (or template) matching distractor appeared, versus did not appear during target search. To explain the inconsistency between findings Gaspelin and Luck (2019) suggested that repeated exposure to a specific non-target feature can reduce neuronal gain for those feature values before stimulus onset in order to effectively reduce processing of feature-matching inputs. Gaspelin and Luck (2019) proposed that when a salient non-target feature can be reliably predicted, its saliency signal can be *proactively suppressed*, whereas when a salient distractor feature cannot be reliably predicted, the distractor must first be selected before it is *reactively suppressed.*

It should be noted that Gaspelin and Luck's (2019) account for what triggers reactive, or proactive suppression was exclusively grounded in findings derived from colour singleton search paradigms. The authors themselves called for research into the neural dynamics that underpin template-guided-suppression for real world objects. Real world features such as facial valence may be subject to controlled suppression through somewhat different neuro-mechanistic underpinnings even when a non-target feature can be reliably predicted. Indeed, Bretherton et al. (2017) evidenced

that despite face stimuli never appearing as targets, proactive suppression did not occur. This suggests that the socio-motivational status of faces may prevent or at least impede their utility as t-f-r. For the current experiment, neutral facial valence will be a t-f-r, or t-f-s depending on experiment block. Lateralised ERP components will be isolated with respect to the evoking stimulus through use of a Hickey et al. (2009) style search array. The current experiment will thereby, explore the sequence of neurocognitive response evoked during social cue guided suppression.

In addition to Bretherton et al's. (2017) N_D and P_D component findings, the authors reported evidence for possible task-related modulation of the Ppc component. Typically reported as an early sensory index (e.g., Luck & Hillyard, 1994a), the Ppc component normally evokes within the P1 time range (75-125ms) and appears maximal in amplitude at lateral occipital scalp sites contralateral, as compared with ipsilateral to the location of singletons. Luck and Hillyard (1994a) reported that modulation of the Ppc component typically corresponds to low level stimulus-driven processes, evoked by lateral sensory display imbalances. Other research findings (e.g., Fontier-Gauthier, Moffat, Dell' Acqua, McDonald, & Jolicoeur, 2012; Leblanc, Prime, & Jolicoeur, 2008) have suggested that the component reflects pre-attentive identification of salient featural discontinuities to facilitate subsequent controlled attentional deployment. Intriguingly, Bretherton et al. (2017) uncovered evidence that Ppc laterality divergence increased under conditions of high, versus low perceptual load. The authors proposed that to optimise task performance, participants exerted strategic continuous controlled suppression when perceptual load was high, to increase the likelihood that search distractors would be suppressed. The suggestion that the Ppc component may additionally reflect preparatory inhibition differs to previous accounts (e.g., Fontier-Gauthier et al., 2012; Leblanc et al., 2008; Luck & Hillyard, 1994a); however, other findings also suggest that task factors may modulate the profile of the Ppc component. Jannati et al. (2013) reported that lateral distractors, but not targets, were associated with Ppc laterality divergence from 120-180 ms post-stimulus onset, though note the late onset of the Ppc response in Jannati et al's (2013) findings. This late onset may have increased the likelihood of early attention contributions to the profile of the Ppc. The current lack of consensus regarding neurocognitive function indexed by the Ppc component highlights a need for its profile to be examined with respect to possible modulation by both perceptual and task-driven factors. If strategic preparation of neural networks for attentional suppression can at least sometimes

be reflected in Ppc laterality divergence, then the current findings may reveal modulated Ppc laterality divergence according to task.

In addition to investigating Ppc and attention component modulation, a final component termed the SPCN was of present interest. The sustained posterior contralateral negativity (SPCN) emerges from around 400ms after the onset of a stimulus and depicts a more negative amplitude response over the contralateral, relative to ipsilateral hemisphere in relation to the evoking stimulus (see: Jolicœur, Brisson, & Robitaille, 2008; Jannati et al., 2013). Converging studies suggest that the component reflects encoding and maintenance of information in visual short-term memory (VSTM; e.g., Dell'Acqua, Sessa, Jolicoeur, & Robitaille, 2006; Jolicoeur, Sessa, Dell'Acqua, & Robitaille, 2006; Klaver, Talsma, Wijers, Heinze, & Mulder, 1999; Vogel & Machizawa, 2004). Holmes et al. (2009) reported that enhanced SPCN contralaterality to emotional (angry and happy), as compared against neutral faces occurred despite no task-related need to maintain facial valence in VSTM. The authors suggested that top-down template signals which work to facilitate maintenance of visual spatial attention toward goal-relevant stimuli (see., Desimone & Duncan, 1995) were triggered in an obligatory fashion by emotion generated feedback loops (see., Vogel & Machizawa, 2004; Pourtois et al., 2013). Holmes et al. (2009) suggested that such a mechanism would have an evolutionary advantage for monitoring potentially significant environmental events; they proposed that the SPCN may represent a partial continuation of the N2pc component so that some degree of continued attentional selection was indexed by the SPCN. This supports previous findings that suggest attention can work in a number of neurocognitive subsystems, such as working memory or perception (see Luck & Hillyard, 1999). In another study Jannati et al. (2013) found that contralaterality of the SPCN (400-800ms post-array onset) diverged for lateral targets, but not for lateral distractors, suggesting that the profile of the SPCN may index controlled uploading and maintenance of representations in VSTM in response to task goals.

Converging investigations appear to suggest that both the emotional salience (Holmes et al., 2009) and task-relevance (Jannati et al., 2013) of stimuli may modulate contralateral negativity divergence during the SPCN interval. Current research, at least that was known of at the time of writing, has focused investigation of the SPCN component on stimuli presented amongst multiple items. This removes the possibility for identifying potential sub-components of the SPCN.

In relation to another late component, Feldmann-Wüstefeld and Vogel (2019) recently uncovered evidence that the negatively lateralised contralateral delay activity (CDA component), which is known to modulate according to visual working memory (VWM) demands and capacity (Vogel & Machizawa, 2004), appears also to reflect the summed response of at least two sub components. Feldmann-Wüstefeld and Vogel (2019) revealed that the profile of the CDA's sustained processing response (recorded from 350-750ms after array onset) evoked by to-be-memorised targets, versus to-be-ignored distractors, corresponded to a contralateral negativity, versus positivity, respectively. The authors suggested that analogously to the P_D and N_T sub-components of the N2pc (Hickey et al., 2009), the classical CDA may also reflect the summed response of negative and positive contributions. Feldmann-Wüstefeld and Vogel (2019) proposed that negative deflections may underpin a process by which target features receive high weights on a priority map so that they are more likely to be encoded into WM; whereas positive deflections may underpin lingering negative weights at suppressed locations to prevent encoding into WM and potential interference with relevant content (Feldmann-Wüstefeld & Vogel, 2019). These findings prompt exploration into the possibility that current use of a Hickey et al. (2009) style array could uncover evidence that the classical SPCN may too reflect the sum of multiple component contributions.

A sparse search array was used for the current experiment two. One face appeared above, or below and the other face to the left or right with respect to a central fixation cross. Of eight possible individuals, one would appear with neutral facial expression (neutral template), the other with either disgust, happy, sad, or surprised facial expression (emotional stimulus). The design was chosen to allow isolation of attentional processing (i.e. attentional selection or inhibition) elicited in response to the lateral template, or lateral emotional stimulus. It was proposed that if the behavioural findings of experiment one were replicated in experiment two, then interpretation may be clarified because experiment two will allow the profile of the ERP response to be isolated with respect to the evoking stimulus.

The aims of the second experiment of the thesis are to clarify:

1) What the impact of emotionally salient distractors will be when neutral valence is a t-f-s. It was considered likely that the previous experiment findings showed that attention was initially captured by the emotional distractor stimulus (N2pc contralateral to the emotional distractor), but that the early attentional capture response was then suppressed (P_D contralateral to the emotional distractor) and the neutral target was selected (N_T contralateral to the neutral target), as reflected by the N2pc flip that was observed in the ERP profile of response for the experiment one neutral t-f-s condition. The use of a Hickey et al. (2009) style array in experiment two will allow the profile of ERP response to be isolated to the lateral stimulus because only one face (either the neutral t-f-s or an emotional distractor) will ever appear at lateral (left or right) location.

Neutral t-f-s condition:

a) If emotional distractors initially capture attention irrespective of task goals then during the first attention interval (134-180ms) there should be a significant contralateral negativity (N_D) contralateral to emotional distractors, that is reduced contralateral to neutral t-f-s inputs (significantly smaller N_T laterality divergence) because neutral faces have lower salience than emotional faces.

b) If attentional capture by emotional distractors is subsequently suppressed so that neutral t-f-s can be attentionally selected then during the second attention interval (230-260ms) there should be a contralateral positivity (P_D) opposite the emotional distractor stimulus, versus a contralateral negativity (N_T) opposite the neutral t-f-s.

A pattern of effects in this direction would provide confirmatory support for the interpretation of neutral t-f-s findings from experiment one of this thesis.

2) Whether the ERP profile of response for the experiment one neutral t-f-r condition was driven by c) proactive and continued suppression of the neutral t-f-r stimulus (early P_D contralateral to the neutral t-f-r that was actively maintained throughout the attention

epoch), or d) early attentional capture by the more salient emotional face (overwhelming N_T contributions to the observed N2pc contralateral to the emotional target) that was not subject to subsequent suppression because on neutral t-f-r trials the more emotional stimulus was also the search target.

Neutral t-f-r condition:

c) would be confirmed by the presence of a significant contralateral positivity (P_D indexed suppression) opposite the laterally presented neutral t-f-r. This direction of effects would indicate proactive template-guided suppression which would involve attentional control.

d) would be confirmed by the presence of a contralateral negativity that is larger opposite the emotional target (N_T) than contralateral to the neutral t-f-r (N_D). A pattern of effects in this direction would indicate that attention was not controlled to actively avoid neutral t-f-r inputs (as would be indexed by a P_D contralateral to the t-f-r), but was instead captured by the more salient (emotional target) stimulus so that fewer resources were available for attentional selection of the less salient (neutral t-f-r) stimulus.

3) It has been well documented that early PPc laterality divergence reflects low level stimulus driven processing that corresponds to sensory imbalances on visual search displays, or early identification of salient feature discontinuities (see Fontier-Gauthier et al., 2012; Leblanc et al., 2008; Luck & Hillyard, 1994a); however, a recent study (Bretherton et al., 2017) reported evidence that strategic continuous suppression may have accounted for increased PPc laterality divergence when perceptual task demands were high, compared to low as a means to improve the chance that search distractors would still be suppressed when task conditions were more challenging. The current experiment will use emotional distractor faces, which have higher socio-motivational salience than the neutral template matching faces. It is expected that the neutral t-f-s task (which requires that emotional faces be avoided) will be more cognitively challenging than the neutral t-f-r task (which requires that emotional faces be selected). If attention can be controlled to avoid saliency-driven processing, then the current experiment two may reveal continuous increased suppression (larger

Ppc laterality divergence) in the harder t-f-s task (requiring that attentional selection of emotional faces is suppressed), compared with the easier t-f-r task (requiring attentional selection of emotional faces). However, if attention cannot be controlled to avoid saliency-driven processing, which may occur due to emotion-driven sub-cortical influences on attention, then Ppc laterality divergence may only be expected to reflect pre-attentive identification of salient feature discontinuities and may not modulate in response to task factors.

4) Based on the findings of previous research (Feldmann-Wüstefeld & Vogel, 2019; Holmes et al., 2009; Jannati et al., 2013) it was suggested in the introduction to the current experiment that as with the N2pc and CDA components, the classical SPCN component may also reflect the sum of multiple sub-components. If the SPCN can both enhance and prevent continued engagement with the visual representation of search items in line with task goals, then this should be reflected by:

e) sustained contralateral positivity opposite neutral t-f-r, versus sustained contralateral negativity opposite neutral t-f-s.

With respect to the emotional stimulus inputs, predicted SPCN modulation takes into account that exogenous (saliency-driven) processing will likely increase encoding and maintenance of emotional valence in comparison to neutral valence. It is therefore predicted that:

f) there will be a sustained contralateral negativity opposite the emotional target (midline t-f-r trials) which will be enhanced in comparison to that measured opposite neutral t-f-s. A sustained contralateral positivity is expected opposite emotional distractor inputs (midline t-f-s trials). This may be enhanced in comparison to neutral t-f-r if an increased suppression response is required to prevent continued engagement with emotion, versus neutral template-matching inputs. Alternatively, sustained inhibition may be comparatively reduced for emotion, versus neutral inputs. This would suggest that controlled suppression may be improved by the availability of a t-f-r, and inputs with high socio-motivational salience may be more resistant to suppression.

5) It is possible that the valence of the emotional face will modulate the extent to which saliency-driven processing occurs. This is because happy, sad, surprised and disgusted valence represent different socio-motivational value. It is possible that the previous experiment findings reflected the sum of differential valence specific responses. The current ERP analysis will include valence of the emotional face as an additional factor.

3.2: Methods:

3.2.1: *Participants*

A statistical power analysis was performed (using GPower 3.1.9.4) for sample size estimation. The statistical values were the same as those used for the experiment one power calculation (based on the previously published findings of Holmes et al., 2009); however, as experiment two included additional repeated measures factors (experiment two was an 2 x 2 x 2 x 4 x 5 repeated measures ANOVA, whereas experiment one was an 2 x 2 x 2 x 4 repeated measures ANOVA), more conservative required alpha and power values were entered ($p < .01$, power = .85) in place of the previously entered alpha and power values ($p < .05$, power = .80). The previously used effect size and partial eta squared values re-entered for the experiment two power analysis ($F = 3.25$, $\eta p^2 = .17$). The projected sample size with this effect size was N = 20 for this within group comparison. A sample size of N > 20 was therefore, sought. Unfortunately, because the data for experiment two was collected outside term time participant recruitment was more challenging. In total seventeen healthy volunteers were recruited. Informed consent was given before the start of the experiment. Two participants were excluded due to low accepted trial numbers after artefact rejection (>25% rejected trials) for horizontal and vertical eye movements. The fifteen remaining participants (4 male; mean ± SD age = 19.87 ± 3.98 years), were all right handed and all reported normal or corrected-to-normal vision. The experiment was performed in compliance with The University of Roehampton ethical and research guidelines and was approved by the University ethics committee.

3.2.2: *Stimuli and Apparatus*

Simultaneously presented face pairs (greyscale stimuli taken from the NimStim Set of Facial Expressions (available at http://www.macbrain.org/faces/) Tottenham et al., 2009) comprised two (one above or below fixation, the other to the left or right of fixation) of eight possible face IDs, with one photograph portraying a neutral expression (select template/inhibit template) and the other photograph portraying a sad, surprise, disgust, or happy expression at equal probability. A total of 768 experiment trials (384 per block) were selected in random order from 768 different ID x emotion x midline position x lateral position x template position x sex combinations, reset at the start of experiment blocks for each participant. Sex of the target and distractor stimuli (female-

female/male-male/female-male) were presented at equiprobable left or right, above or below fixation locations. Participants completed 32 practice trials (16 select / 16 inhibit) with accuracy and response time feedback. The practice trials could be repeated to achieve a minimum of 70% accuracy before beginning the main experiment. The face stimuli and stimulus dimensions, including distance from central fixation, were adapted from Holmes et al. (2009); for the purpose of the practice and main experiment trials of the current experiment, faces were cropped in an oval shape (2.65cm wide × 3.25cm high) to remove hair or clothing and subtended 3.99° x 4.3° of visual angle. To isolate target versus distractor contributions to the observed ERP component and to reduce trial numbers and therefore, experiment duration and participant fatigue, stimulus displays were adapted from the six visual angle positions used by Hickey et al. (2009) (60°, 120°, 240°, 300°) wherein horizontal stimuli appeared marginally above or below the horizontal midline, to four visual angle positions (90°, 180°, 270°, 360°), so that one face appeared directly above or below fixation, whilst the second face appeared directly to the left or right with respect to fixation. Analogous to Holmes et al. (2009), the centres of the faces were presented 25 mm from the centre of a grey (184 cd/m²) central fixation cross (6mm x 6mm) against a dark grey (9 cd/m²) background. The faces within each face pair were equated for mean luminance and root mean square (RMS) contrast energy. Mean luminance energy was calculated for each face stimulus, then equated across all face stimuli. Total RMS energy for each luminance equated face was then calculated, and the luminance value at each pixel from each face was divided by that value (using standard routines in Matlab 6), resulting in a mean luminance value of 7.83 cd/m2, and Michelson contrast of .934.

Participants were seated in a dark cubicle, 55 cm from a 17-in. ViewSonic G220f computer screen with a refresh rate of 75Hz, connected to a Dell precision Pentium IV computer. E-Prime Psychology Software 2.0 (Schneider, Eschman & Zuccolotto, 2002) was used for stimulus presentation and response collection. Responses were indicated via a purpose built response box.

3.2.3: *Procedure*

Experiment trials (see Figure 1 for example trial sequence) started with a central fixation cross for 500ms, followed by a face pair (see Stimuli and Apparatus for face pair configurations) for

600ms. Responses were collected from the start of face pair onset to the end of a proceeding blank screen inter stimulus interval (ITI) for 1500 or 1800 ms at random to prevent habituation.

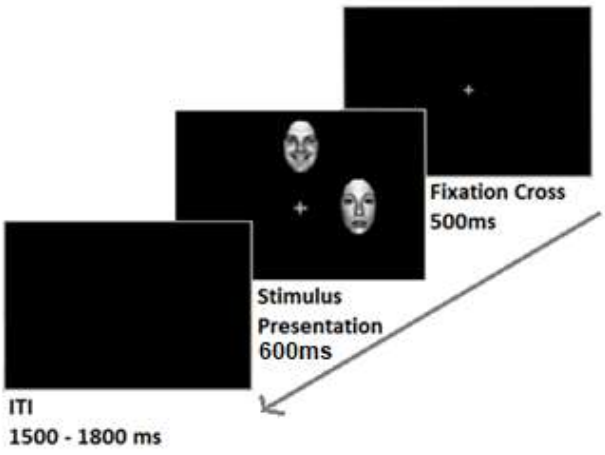


Figure 3.1 Example of select lateral template with midline happy valence distractor. Trial sequence with timings depicted. *Stimuli not to scale.*

The participants were randomly allocated to receive the select template block prior to the inhibit template block, or vice versa. An instruction screen directed participants to indicate as quickly and accurately as possible, the sex of the neutral face (select template block), or the non-neutral face (inhibit template block). Sex of the target face was indicated using the index and middle finger of the dominant hand and buttons one and two (counterbalanced across participants) on a purpose built response box. Approximately every 68 seconds participants received an on-screen instruction to take a short break and press the space-bar when ready to continue.

3.2.4: *EEG Data Acquisition*

EEG was recorded from 32 Ag-AgCl electrodes (Fp1, Fp2, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T8, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, O1, Oz, O2, PO7, PO8, PO9 and PO10 (according to the 10-20 system)), referenced on-line to the vertex and then re-referenced off-line to the average of the left/right mastoids. Horizontal EOG (HEOG) was recorded bipolarly from the outer canthi of both eyes and vertical EOG (VEOG) was recorded bipolarly,

above the brow and below the left eye. See Figure 3 for electrode layout. All electrode impedances were kept below 5 kΩ; EEG and EOG were digitised with a 500 Hz sampling rate. The EEG was filtered online at d.c. to 100 Hz with vertex (CZ) as the online reference. Following EEG recording, data were digitally filtered offline with a bandpass of .3 Hz (24 db/oct) to 30 Hz (24 db/oct; zero-phase shift) using Neuroscan software (version 4.5). EEG and HEOG were then epoched into 600ms intervals, from 100ms before (pre-stimulus baseline) to 500ms after face pair onset. Trials with lateral or vertical eye movements (HEOG/ VEOG exceeding ± 40 μV and ± 80 μV, respectively) and trials with eyeblinks (Fp1/Fp2 exceeding ± 60 μV), or other artifacts (voltage at any electrode exceeding ± 100 μV) measured in each epoch were excluded from the analysis. Epochs were then re-referenced to the average of A1 and A2 ear lobe electrode locations.

Separate averages were computed for all combinations of task (select template, inhibit template) x emotion (disgust, happy, sad, surprised) x template position (lateral, midline). Contralateral ERPs were the average of the left (P7) and right (P8) hemisphere electrodes for lateral stimuli presented to the right and left visual fields, respectively. Ipsilateral ERPs were the average of the left (P7) and right (P8) hemisphere electrodes for lateral stimuli presented to the left and right visual field, respectively; therefore, contralateral versus ipsilateral ERPs were the opposite versus same-sided hemisphere to the lateral stimulus. Electrodes P7 and P8 were selected for analysis because contralaterality effects were maximal at those sites.

3.2.5: Component time-window selection

Initially it was intended that ERP components would be selected using a commonly employed statistical approach that identifies where contralateral minus ipsilateral amplitude difference is greatest (for similar approaches see: Luck & Gaspelin, 2017; Sawaki et al., 2012). In practice a series of one-sample t-tests were run comparing the mean amplitude measured at each time point with the previous time-point (sample taken every two milliseconds). Time-windows were categorised as beginning after and ending before two consecutive t-tests with $p < .001$. Only two time-windows (post-stimulus intervals: 72-74ms and 148-158ms) met the stringent $p < .001$ criterion for selection. When a more liberal $p < .05$ cut-off was used this resulted in identification of six time-windows where laterality (contralateral minus ipsilateral difference) significantly diverged:

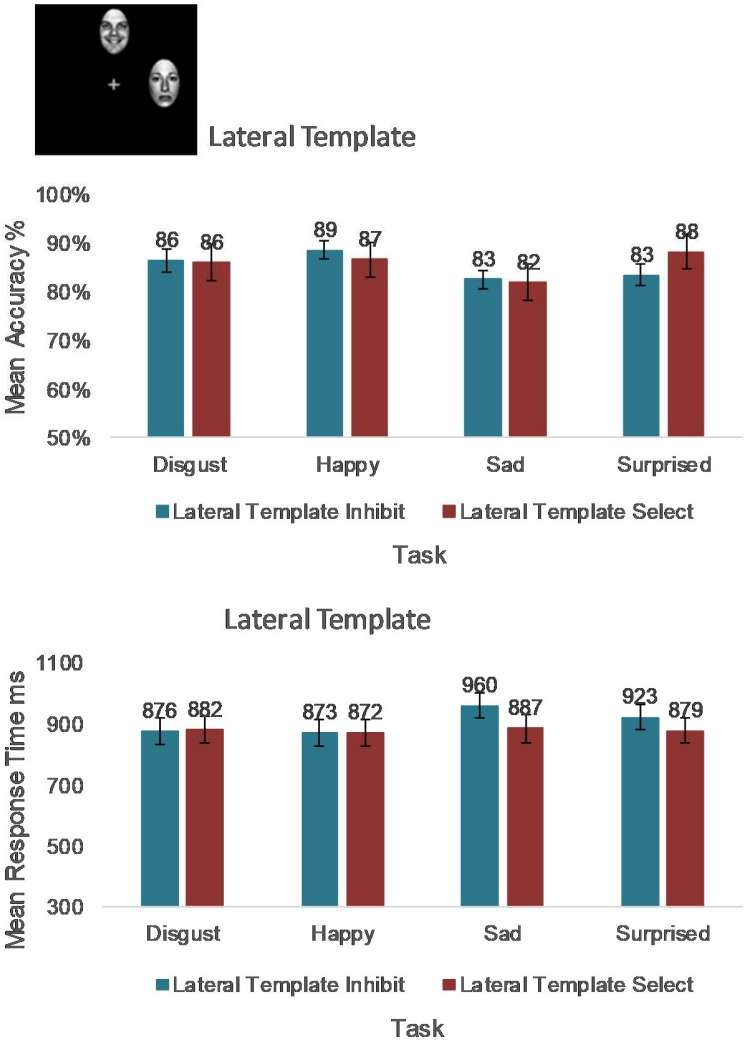
24-26ms, 66-100ms, 134-168ms, 352-368ms, 410-418ms, 452-500ms. The first (24-26ms) was short and too early to reflect attention related cognitive processing and was therefore, disregarded. Visual inspection of the ERP wave-form suggested the presence of at least one additional attention related ERP component (between approx. 230-260ms) though this interval was not identified statistically. The final three time-windows that were identified statistically (352-368ms, 410-418ms and 452-500ms) appeared to reflect laterality divergence fluctuation within a single late component as the ERP wave-form depicted laterality divergence from approx. 300ms post-stimulus onset that continued till the end of the epoch. To overcome the issues outlined ERP components were instead selected by visual inspection of the ERP waveforms combined with previous research on contralateral components such as the PPc, early N2Pc, late N2Pc and SPCN (e.g., Bretherton et al., 2017; Fontier-Gauthier et al., 2012; Grubert & Eimer, 2016; Hickey et al., 2009; Holmes et al., 2009; Holmes et al., 2013; Jannati et al., 2013; Woodman & Luck, 2003). This resulted in identification of four ERP component intervals that best represented the modulations of contralaterality effects (i.e., in attention processing) elicited by the current paradigm. Component intervals were as follows: PPc (76-114ms), early attention (134-180ms), late attention (230-260ms) and SPCN (300-500).

3.3: Results

3.3.1: *Behavioural Results*

Non-responses and trials with response times (RTs) below 300ms were discarded; the subsequent mean and standard error of RTs for the sample was: M = 894.12 and SEM = 2.76, respectively. Mean percentage accurate responses (Acc) and mean RTs for each participant, were entered into a repeated measures analysis of variance (ANOVA) with the factors: task (select vs. inhibit), emotion (disgust vs. happy vs. sad vs. surprised), and template position (lateral vs. midline). Note that for the select conditions, participants were given a neutral template-for-selection; no distractor valence information was available. For the inhibit conditions, participants were given a neutral template-for-rejection; no target valence information was available.

Figure 3.3 (next page) depicts the task-driven: inhibit (blue bars), versus select (red bars), Acc (top panel) and RT (bottom panel) means, for trials with lateral templates (left side) and midline templates (right side). Pairs of bars correspond to inhibit versus select template conditions, for stimulus displays with emotion valence: disgust, happy, sad and surprised, respectively.


Lateral Template
Mean Accuracy %
100%
90%
80%
70%
60%
50%
86 86
89 87
83 82
83 88
Disgust
Happy
Sad
Surprised
Lateral Template Inhibit
Lateral Template Select
Task
Lateral Template
Mean Response Time ms
1100
900
700
500
300
876 882
873 872
960 887
923 879
Disgust
Happy
Sad
Surprised
Lateral Template Inhibit
Lateral Template Select
Task

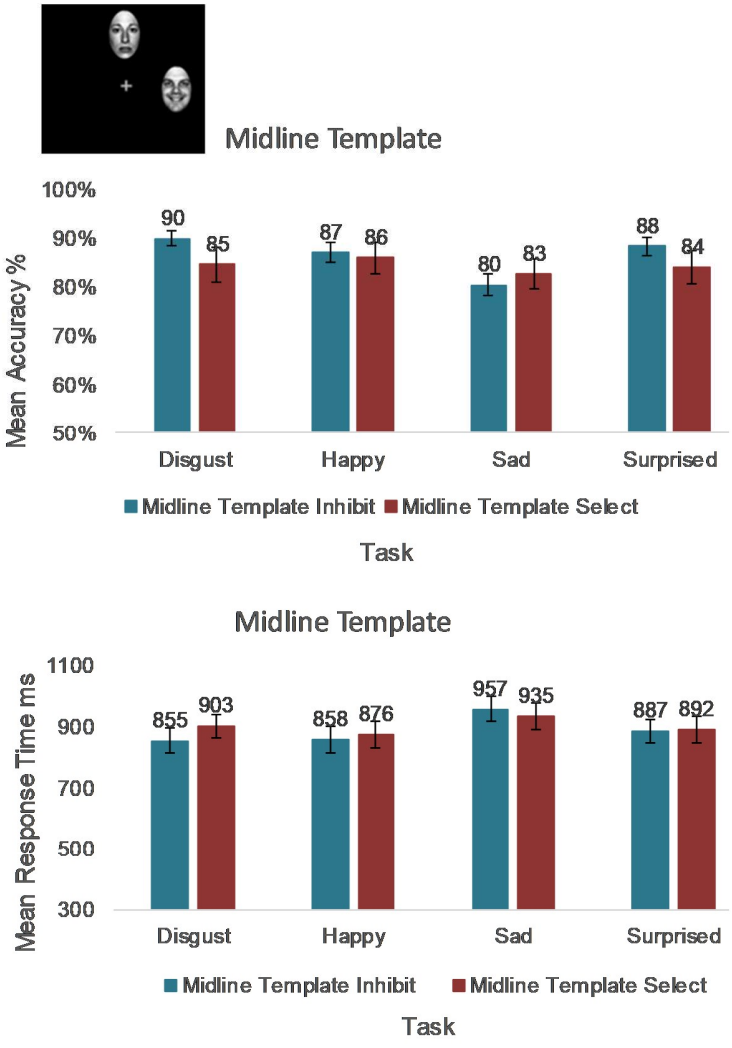

Midline Template
Mean Accuracy %
100%
90%
80%
70%
60%
50%
90 85
87 86
80 83
88 84
Disgust
Happy
Sad
Surprised
Midline Template Inhibit
Midline Template Select
Task
Midline Template
Mean Response Time ms
1100
900
700
500
300
855 903
858 876
957 935
887 892
Disgust
Happy
Sad
Surprised
Midline Template Inhibit
Midline Template Select
Task

Figure 3.3

3.3.1.1: *Accuracy*

There was no significant main effect of task, or template position (both $F \leq 1$); however a main effect of emotion, $F(3,42) = 13.93$, $p < .001$, $\eta p^2 = .5$, revealed that the lowest accuracy was recorded to displays with sad valence ($M = 81.91\%$, $SEM = 2.26$), and increased Acc corresponded to displays with surprised ($M = 86.03\%$, $SEM = 2.1$) and disgust valence ($M = 86.75\%$, $SEM = 2.31$), followed by happy valence ($M = 87.05\%$, $SEM = 2.27$).

There was a significant two-way interaction between the factors task x emotion, $F(3,42) = 3.45$, $p = .03$, $\eta p^2 = .19$; this was subsumed under a significant three-way interaction for task x template position x emotion, $F(3,42) = 4.9$, $p = .005$, $\eta p^2 = .26$. Explication of the three-way interaction was through separate two-way ANOVAs for lateral and midline templates, with the factors: task x emotion.

The lateral template ANOVA, revealed a main effect of emotion, $F(3,42) = 7.51$, $p < .001$, $\eta p^2 = .35$, as sad valence drew the lowest Acc ($M = 82.24\%$, $SEM = 2.48$), with increments according to surprised ($M = 85.82\%$, $SEM = 2.34$), disgust ($M = 86.25\%$, $SEM = 2.42$), then happy valence displays ($M = 87.59\%$, $SEM = 2.4$). There was no main effect of task ($F<1$). A two-way, emotion x task interaction, $F(3,42) = 4.44$, $p < .01$, $\eta p^2 = .24$, was followed up; however, post-hoc t-tests with Bonferroni adjusted alpha level of .0125 per test (.05/4) revealed no significant difference between inhibit, versus select template trials for any of the four emotions (all $p \geq .0125$).

The midline template ANOVA revealed a main effect of emotion, $F(3,42) = 6.38$, $p = .001$, $\eta p^2 = .31$. Sad valence displays drew the lowest Acc ($M = 81.58\%$, $SEM = 2.26$), and increased Acc corresponded to surprised ($M = 86.24\%$, $SEM = 2.14$) and disgust ($M = 86.51\%$, $SEM = 2.22$), then happy valence displays ($M = 87.26\%$, $SEM = 2.36$). No main effect of task was revealed ($F<1$). A two-way emotion x task interaction, $F(3,42) = 4.26$, $p = .01$, $\eta p^2 = .23$, was followed up. Post-hoc t-tests with Bonferroni adjusted alpha level of .0125 per test (.05/4) compared inhibit against select template trials for each emotion, though all comparisons failed to reach significance (all $p \geq .0125$).

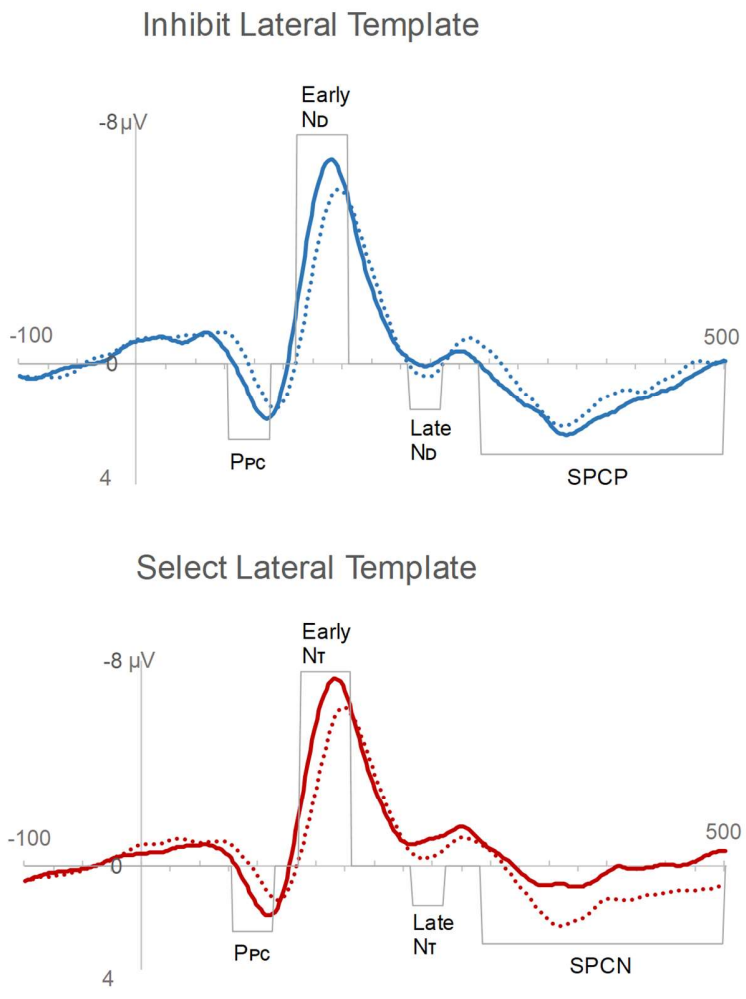
3.3.1.2 *Response Times*

The main effects of task and template position were non-significant ($F \leq 1$); however, there was a highly significant main effect of emotion, $F(3,42) = 29.09$, $p < .001$, $\eta p^2 = .68$, as RT was fastest when displays contained happy valence (M = 869.67ms, SEM = 36.54), and slowed according to displays with disgust (M = 878.86ms, SEM = 34.66), surprised (M = 895.16ms, SEM = 34.25), then sad valence (M = 934.96ms, SEM = 35.22).

There was also a two-way task x emotion interaction, $F(3,42) = 13.22$, $p < .001$, $\eta p^2 = .49$. Post-hoc t-tests with Bonferroni adjusted alpha level of .0125 per test (.05/4) compared inhibit against select template trials for each emotion, though all comparisons failed to reach significance (all $p \geq .0125$).

3.3.2 *Electrophysiological Results*

Incorrect responses, non-responses and RTs below 300ms, were not included in the ANOVA of mean ERP amplitudes. The left side of figures 3.4 and 3.5 show ERPs contralateral (dotted lines) and ipsilateral (solid lines) to the location of the lateral stimulus, observed at lateral parietal-occipital electrode sites P7 and P8. Red lines and blue lines indicate where the lateral stimulus was selected, or inhibited, respectively. The bottom right of figures 3.4/3.5 show the contralateral minus ipsilateral difference waves that correspond to the lateral template (figure 3.4), and to the lateral emotion stimulus on midline template trials (figure 3.5). Indicated on each graph are the component intervals selected for analysis: Ppc (76-114ms), early attention (134-180ms), late attention (230-260ms) and SPCN (300-500). Example stimulus displays and the task instructions that participants' received, appear at the top right of figures 3.4/3.5.



Task Instruction:

Select Template Instruction: 'Report the sex of the neutral face'
Inhit Template Instruction: 'Report the sex of the non-neutral face'

Example of Lateral Template Stimuls Array:

Contralateral to lateral stimulus- solid lines

Ipsilateral to lateral stimulus- dashed lines

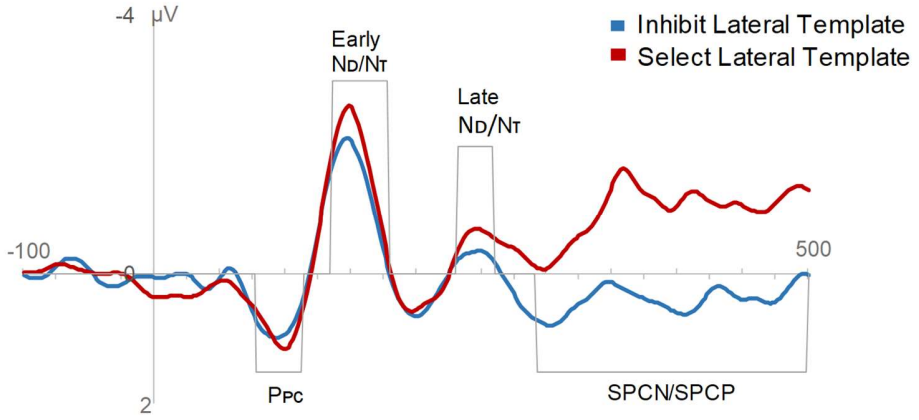
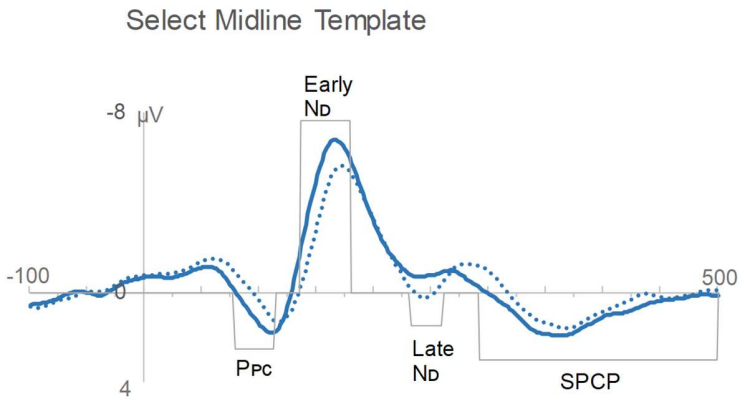


Figure 3.4



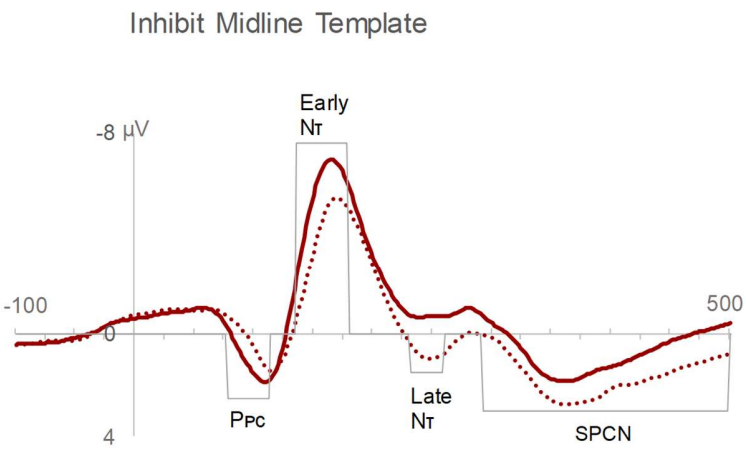
Task Instruction:

Select Template Instruction: 'Report the sex of the neutral face'
Inhit Template Instruction: 'Report the sex of the non-neutral face'

Example of Midline Template Stimuls Array:

Contralateral to lateral stimulus- solid lines

Ipsilateral to lateral stimulus- dashed lines



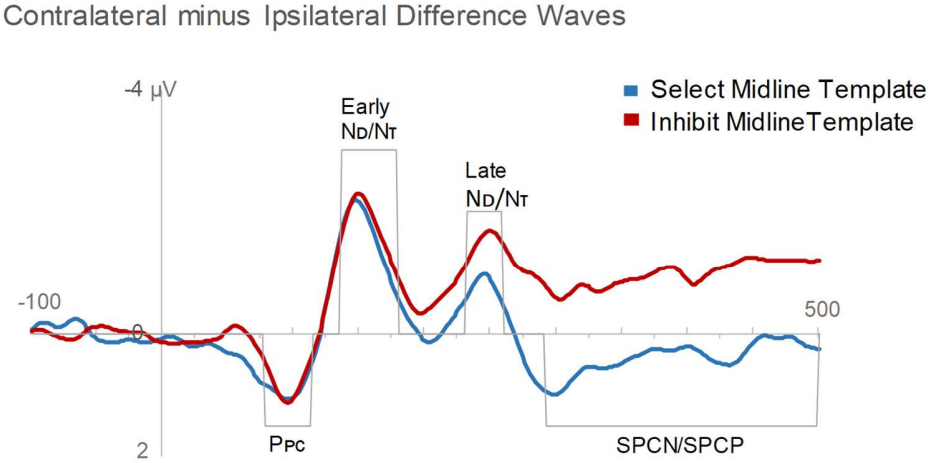


Figure 3.5

3.3.2.1: *ANOVA: all conditions*

Mean ERP amplitudes were entered into a 4 x 4 x 2 x 2 x 2 repeated measures ANOVA with the factors: component (76-114, 134-180, 230-260, 300-500 ms), emotion (disgust, happy, sad, surprised), laterality (contralateral vs. ipsilateral), template position (lateral vs. midline), and task (inhibit vs. select). See experiment methods (*ERP Components*) for details regarding time-window selection. Where post-hoc t-tests were carried out, the Bonferroni correction for adjusted alpha level (.05/number of tests) was applied. Where Mauchley's test for the assumption of sphericity was violated, Greenhouse-Geisser corrected values were reported with degrees of freedom taken from sphericity assumed.

The main effect of laterality was significant, $F(1,14) = 6.04$, $p = .028$, $\eta p^2 = .3$, as mean amplitudes were significantly more negative at contralateral ($M = -1.08\ \mu V$, $SEM = .39$), versus ipsilateral ($M = -.61\ \mu V$, $SEM = .26$) electrode locations. The main effect of component was also confirmed, $F(3,42) = 21.87$, $p < .001$, $\eta p^2 = .61$; mean amplitudes over the 76-114, 134-180, 230-260, and 300-500 ms intervals were: $M = .58\ \mu V$, $SEM = .44$, $M = -4.63\ \mu V$, $SEM = .89$, $M = -.25\ \mu V$, $SEM = .44$ and $M = .9\ \mu V$, $SEM = .34$, respectively. There was no main effect of template position ($F<1$), task, or emotion (both $p \geq .05$). There was a highly significant four-way interaction between the factors: component x laterality x task x template position, $F(3,42) = 21.54$, $p < .001$, $\eta p^2 = .61$. To simplify subsequent analyses and ensure the sequence of neuro-mechanistic underpinnings for template-guided search could be indexed, separate ANOVAs were executed for each component (intervals were: 76-114, 134-180, 230-260, and 300-500 ms). Although the four-way interaction did not include the factor: emotion, there was a two-way emotion x template position interaction, $F(3,42) = 5.11$, $p = .004$, $\eta p^2 = .27$, and a three-way laterality x task x emotion interaction, $F(3,42) = 7.44$, $p < .001$, $\eta p^2 = .35$; for that reason and because valence-driven modulation to template-guided search was hypothesised, emotion as well as laterality, task and template position were included as factors in the subsequent ANOVAs for each component. Where a significant main effect of laterality emerged, the contralateral minus ipsilateral amplitude difference became the dependant variable. Throughout the

results the term 'contralaterality' will be used when the direction (positive, or negative) of the contralateral minus ipsilateral amplitude difference is referred to. The dependent variable change (when applicable) allowed the number of experiment factors to be reduced to simplify the findings.

3.3.2.1.1: *PPc* 76-114 ms

The main effect of laterality was significant, $F(1,14) = 7.5$, $p = .016$, $\eta p^2 = .35$, as mean amplitudes contralateral, versus ipsilateral to the lateral stimulus were $M = 1$ μV, $SEM = .57$ and $M = .16$ μV, $SEM = .32$, respectively; therefore, the contralateral minus ipsilateral difference scores, were entered into a five-way AVOVA with the factors: task, template position, and emotion.

No main effect of task, or template position was revealed (both $F \leq 1$) and the main effect of emotion did not reach significance ($p > .05$). A two-way task x emotion interaction, $F(3,42) = 5.44$, $p = .003$, $\eta p^2 = .28$, was subsumed under a three-way task x template position x emotion interaction, $F(3,42) = 4.42$, $p < .01$, $\eta p^2 = .24$. To unpack the observed interaction effects, difference scores for the factors: task x emotion were entered into separate ANOVAs for template position: lateral and midline.

The ANOVA of lateral template trials, revealed no main effect of task, or emotion (both $F \leq 1$); however, the task x emotion interaction was highly significant, $F(3,42) = 10.72$, $p < .001$, $\eta p^2 = .43$. Post-hoc t-tests with Bonferroni adjusted alpha level of .008 per test (.05/6) compared each level of the factor emotion separately for inhibit and select template trials. Lateral t-f-s trials were associated with greater PPc laterality divergence when happy, compared with disgust valence appeared on the vertical midline (respective means of $M = 1.74$ μV, $SEM = .4$ and $M = .27$ μV, $SEM = .37$, $t(14) = 3.97$, $p = .001$) and when happy, compared with sad valence appeared on the vertical midline (respective means of $M = 1.74$ μV, $SEM = .4$ and $M = .5$ μV, $SEM = .46$, $t(14) = 3.39$, $p = .004$). On lateral t-f-r trials PPc laterality divergence was not significantly modulated by valence of the midline face (all comparisons

exceeded the Bonferroni adjusted alpha level of .008 per test (.05/6)). See appendix D for face stimuli used in the current paradigm.

The ANOVA of midline template trials, revealed no main effect of task, or emotion (F<1 and p>.05, respectively) and the task x emotion interaction was non-significant (F<1).

3.3.2.1.2: *Early attention:* 134-180 ms

The main effect of laterality was highly significant, $F(1,14) = 17.64$, $p = .001$, $\eta p^2 = .56$, as mean amplitudes contralateral, versus ipsilateral to the lateral stimulus were $M = -5.44$ μV, $SEM = 1.04$ and $M = -3.82$ μV, $SEM = .77$, respectively. Therefore, the contralateral minus ipsilateral difference scores were entered into a five-way AVOVA with the factors: task, template position, and emotion.

The main effects of task, template position, and emotion were all non-significant (all $p \geq .05$). A two-way task x template position interaction, $F(1,14) = 4.49$, $p = .05$, $\eta p^2 = .24$, was uncovered; however, post-hoc t-tests (Bonferroni adjusted alpha of .025 per test (.05/2)) revealed no significant difference between the contralateral negativity elicited on inhibit, versus select template trials for template position: lateral (respective means of: $M = -1.4$ μV, $SEM = .42$ and $M = -1.74$ μV, $SEM = .38$, $t(14) = 1.18$, $p = .258$, *ns*), or midline (respective means of: $M = -1.74$ μV, $SEM = .45$ and $M = -1.57$ μV, $SEM = .44$, $t(14) = -.89$, $p = .388$, *ns*).

No further interaction effects reached significance (all $p \geq .05$).

3.3.2.1.3: *Late attention:* 230-260 ms

The main effect of laterality was non-significant, $F(1,14) = 3.38$, $p = .088$, $\eta p^2 = .19$, *ns*; however, attention effects were investigated as there was a significant three-way laterality x task x template position interaction, $F(1,14) = 6.85$, $p = .02$, $\eta p^2 = .33$. Follow-up ANOVAs were performed separately for template position: lateral and midline, with laterality x task entered as factors.

The lateral template ANOVA observed a main effect of task, $F(1,14) = 11.6$, $p = .004$, $\eta p^2 = .45$; as mean amplitudes were positive, versus negative for inhibit, versus select template trials ($M = .1$ μV, $SEM = .46$ and $M = -.74$ μV, $SEM = .52$), respectively; however, the crucial main effect of laterality failed to reach significance, $F(1,14) = 1.07$, $p = .32$, $\eta p^2 = .07$, *ns*.

The midline template ANOVA revealed no main effect of task, $F(1,14) = 2.78$, $p = .118$, $\eta p^2 = .17$, *ns*; however, a significant main effect of contralaterality was observed, $F(1,14) = 4.97$, $p = .043$, $\eta p^2 = .26$, as mean amplitudes contralateral, versus ipsilateral to the lateral stimulus were $M = -.74$ μV, $SEM = .42$ and $M = .38$ μV, $SEM = .56$, respectively. The two-way task x laterality interaction approached significance, $F(1,14) = 4.04$, $p = .064$, $\eta p^2 = .22$, *ns*. Post-hoc t-tests with Bonferroni adjusted alpha level of .025 per test (.05/2) revealed that respective contralateral, versus ipsilateral means significantly diverged when neutral faces were templates-for-rejection and the task thereby required that the lateral stimulus be attended: $M = -.73$ μV, $SEM = .4$ and $M = .77$ μV, $SEM = .54$, $t(14) = -2.85$, $p = .013$. In contrast, the same comparison did not approach significance when neutral faces were templates-for-selection and the task thereby required that the lateral stimulus be ignored: $M = -.76$ μV, $SEM = .49$ and $M = -.01$ μV, $SEM = .62$, $t(14) = -1.37$, $p = .191$, *ns*.

No further interaction effects were of relevance to the hypotheses.

3.3.2.1.4: *Late sustained processing interval*- 300-500 ms

The main effect of laterality was significant, $F(1,14) = 4.66$, $p = .049$, $\eta p^2 = .25$, as mean amplitudes were less positive at contralateral ($M = .74$ μV, $SEM = .31$), versus ipsilateral ($M = 1.06$ μV, $SEM = .37$) electrode locations. The contralateral minus ipsilateral difference scores were therefore, entered as the dependant variable into a three-way AVOVA with the factors: task, template position and emotion.

There was no main effect of task, template position, or emotion (all $p \geq .05$); however, there was a highly significant two-way task x template position interaction, $F(1,14) = 63.91$, $p < .001$, $\eta p^2 = .82$, that was deconstructed through post-hoc t-tests with Bonferroni adjusted alpha .025 per test (.05/2). A contralateral positivity, versus contralateral negativity was recorded in response to lateral template inhibition, versus selection (respective means of: $M = .37$ μV, $SEM = .18$ and $M = -1.06$ μV, $SEM = .22$, $t(14) = 5.86$, $p < .001$). Similarly, a contralateral positivity, versus contralateral negativity was observed when midline templates were selected, versus inhibited (respective means of: $M = .36$ μV, $SEM = .22$ and $M = -.98$ μV, $SEM = .17$, $t(14) = 6.44$, $p < .001$). The magnitude of the task-driven difference was not significantly modulated by the template status of the lateral face: difference scores were calculated separately for lateral template (select minus inhibit was $M = -1.43$ μV, $SEM = .25$) and midline template (inhibit minus select was $M = -1.35$ μV, $SEM = .21$) trials; however, $t(14) = -.3$, $p = .768$, *ns.* There was also no significant difference between the magnitude of the lateral stimulus suppression response on lateral t-f-r, versus midline t-f-s trials (respective means of $M = .37$ μV, $SEM = .18$ and $M = .36$ μV, $SEM = .22$, $t(14) = .05$, $p = .96$, *ns*). Similarly, no significant difference was revealed between the magnitude of the lateral stimulus selection response on lateral t-f-s, versus midline t-f-r trials (respective means of $M = -1.06$ μV, $SEM = .22$ and $M = -.98$ μV, $SEM = .17$, $t(14) = -.417$, $p = .683$, *ns*).

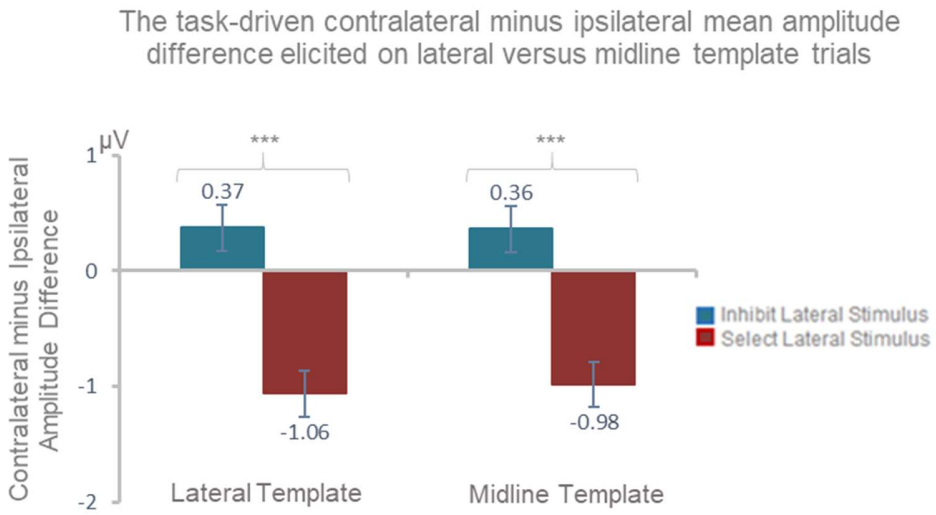


Figure 3.6 demonstrates the lateral stimulus elicited, task x template position interaction. Contralateral minus ipsilateral difference scores appear above the bars. Blue versus red bars depict lateral stimulus inhibition versus selection, respectively. Error bars denote the mean lateral stimulus inhibition error (overlaid on blue bars) and mean lateral stimulus selection error (overlaid on red bars). Significance level is indicated above the brace. A highly significant contralateral positivity, versus contralateral negativity, was observed on inhibit lateral template and select midline template trials (blue bars), versus select lateral template and inhibit midline template trials (red bars), respectively.

3.3.3: *Behavioural Results Summary*

3.3.3.1: *Accuracy and Response Times*

Irrespective of task, behavioural performance was most impaired when sad valence appeared during search. Faster and more accurate responses were associated with the presence of surprise, disgust, then happy valence, respectively.

The behavioural measures demonstrate that while Acc and RTs may usefully illustrate factors that modulate behaviour, neuro-mechanistic processing that underpins task performance may be better investigated through neurophysiological methods that can sensitively index early stages of attention processing.

3.3.3.2: *Electrophysiological Results Summary*

3.3.3.2.1: *Ppc:* 76-114 ms

There was no main effect of task and therefore, no evidence for increased strategic continuous suppression under the more challenging t-f-s, versus t-f-r condition.

Neutral t-f-s were instead associated with enhanced Ppc laterality divergence when displays contained happy facial valence, compared with disgust and sad facial valence. The pattern of effects likely emerged because local feature discontinuities were greater between neutral and happy face stimuli, when compared against neutral and disgust/sad face stimuli (see appendix D for face stimuli used in experiment two).

3.3.3.2.2: *Early attention:* 134-180 ms

The Nd/Nt (selection) response to the lateral stimulus was not modulated by task, or valence of the non-template face. The finding suggests that the visual representation of stimuli was enhanced during the 134-180 component interval, irrespective of task goals or saliency factors.

3.3.3.2.3: *Late attention:* 230-260 ms

There was significant laterality divergence indicating attentional selection when the lateral non-template face was attended (midline t-f-r), versus ignored (midline t-f-s). The findings suggests some evidence of goal-directed processing.

3.3.3.2.4: *Late sustained processing interval* 300-500 ms

A contralateral positivity (indicating attentional suppression at the location of the lateral face) was observed for lateral t-f-r and midline t-f-s trials; whereas a contralateral negativity (indicating attentional selection at the location of the lateral face) was observed for lateral t-f-s and midline t-f-r trials. There was no significant difference between the selection or suppression response according to whether the lateral stimulus was a template, or non-template face. This suggest that: a) the classical SPCN likely reflects the summed contributions of positive (suppression) and negative (selection) sub-components; b) continued engagement and VWM maintenance of face stimuli was enhanced, or prevented according to task-goals and this was irrespective of socio-motivational saliency factors.

3.4: Discussion

The previous experiment of the thesis uncovered faster reaction times when neutral faces were t-f-r, compared to t-f-s. Also revealed was a contralateral positivity to neutral t-f-r that was sustained throughout the ERP profile, indicating sustained inhibition. Initially, the behavioural and ERP findings were interpreted as evidence of a t-f-r benefit. It was proposed that participants successfully utilised neutral valence as a t-f-r to suppress allocation of attention toward faces with template-matching features. However, in contrast to the initial explanation of the findings, it was alternatively proposed that ignoring the neutral face on t-f-r trials would likely have been greatly facilitated by saliency-driven attentional prioritisation of the adjacent emotionally valanced face. A large contralateral negativity to (attentional selection of) the adjacent emotional face would look the same as a contralateral positivity to (inhibition of) the neutral t-f-r. Indeed, emotionally salient stimuli such as threat-related stimuli, have been previously shown to receive attentional prioritisation, evidenced by increase N2pc contralaterality to emotional, compared with neutral faces (see: Holmes et al., 2014). As the profile of the ERP response observed during the previous experiment reflected the sum of neutral template and emotional stimulus processing, sub components of the observed N2pc response could not be dichotomised.

Analogous to the sparse search array employed by Hickey et al. (2009), the current experiment two displayed one face above or below and the other face to the left or right with respect to a central fixation cross. Of eight possible individuals, one appeared with neutral valence (neutral template), the other with either disgust, happy, sad, or surprised facial expression (emotional stimulus). The chosen design allowed isolation of attentional processing elicited in response to the lateral template, or lateral emotional stimulus, according to task goals.

It was proposed that if the behavioural findings of experiment one, namely a t-f-r benefit, were replicated in experiment two, then interpretation may be clarified through isolation of the corresponding neurophysiological underpinnings. With respect to the neutral t-f-s findings of experiment one, an N2pc flip (first described by Woodman & Luck, 1999) was interpreted as evidence that attention had first been captured by the emotional face before attentional capture was suppressed so that the neutral t-f-s could be attended. For attention component intervals,

suppression, versus selection would be indexed by a contralateral positivity, versus negativity, respectively. In addition, possible Ppc component modulation by task difficulty as well as perceptual factors, was of interest because recent findings (Bretherton et al., 2017) suggest the Ppc may index strategic continuous suppression to improve the likelihood of distractor inhibition under challenging task conditions. Lastly, the SPCN component was explored with respect to possible sub-component contributions to its classical profile because a) research findings have revealed goal-related modulation of SPCN laterality divergence (e.g., Holmes et al., 2009; Jannati et al., 2013) and b) a recent study (Feldmann-Wüstefeld & Vogel, 2019) found that a similar component (the CDA) actually reflects the summed response of positive and negative sub-components. Potential emotion specific variation between neuro-cognitive processing during template-guided search was also explored.

3.4.1 *Behavioural findings*

An aim of experiment two was to clarify whether the t-f-r benefit observed for the experiment one neutral template condition, was driven by controlled suppression of the neutral t-f-r, or by exogenous (saliency-driven) prioritisation of the emotional face. Previous findings (see Vuilleumier et al., 2003) have evidenced rapid sub-cortical activation triggered by emotional faces which, via feedforward mechanisms, can heighten activation of attention networks for processing emotionally salient inputs. Therefore, rather than neutral t-f-r faces having to be actively suppressed, participants may have been able to successfully complete the task through exogenous processes with little influence from endogenous control networks. As such, the t-f-r benefit observed in the experiment one behavioural data may not have been driven by controlled goal-driven suppression of neutral t-f-r, but instead by automatic saliency-driven emotional input selection.

In contrast to experiment one, the current experiment two data did not uncover a t-f-r benefit to response times or to accuracy. In fact task (t-f-r vs. t-f-s) did not modulated behavioural performance in experiment two. Despite the issue that the current Hickey et al. (2009) style paradigm would therefore, not be able to reveal the neuro cognitive underpinnings of the t-f-r benefit observed in experiment one, it was of interest that behavioural performance was maintained between the tasks in experiment two. A previous t-f-r study (Bretherton et al., 2017) noted that under conditions of high perceptual load behavioural performance was maintained irrespective of

distractor face valence (angry vs. neutral), though valence-driven processing differences were observed on the ERPs. Bretherton et al. (2017) found that early attentional capture (indexed by an early ND) was present only in response to the angry distractor. There was no evidence of early capture in response to the neutral distractor. Early capture in response to angry valence was subsequently suppressed (PD opposite the angry distractor); this occurred during the same interval wherein attentional selection at the location of neutral distractors was proactively suppressed (PD indexed suppression contralateral to the neutral distractor without a prior selection (capture) response). The findings demonstrate that ERPs can elucidate the neurocognitive underpinnings that at least sometimes allow behavioural performance to be maintained despite obvious differences in task difficulty. As the same post-stimulus intervals were analysed between the current t-f-s and t-f-r conditions, it will be possible to uncover critical stages in the post-stimulus response where attention processing may have modulated differently for changing task demands, accounting for the consistency in behavioural performance observed between the current t-f-s and t-f-r tasks.

Regarding the difference in task-related behavioural findings between experiment one and two, it is possible that the design of the current paradigm, wherein one stimulus appeared directly above central fixation, decreased inter-stimulus competition. Both stimuli presented on the previous bilateral array would have mapped onto ventral processing areas, whereas the current midline stimulus would have mapped onto dorsal areas. While this paradigm related processing change may have decreased inter-stimulus competition in experiment two, the use of the current Hickey et al. (2009) style sparse array is still of great use for improving the level of certainty that can be achieved with respect to unpacking the sub-components that contribute towards classical ERP components.

Although no task-related modulation was revealed by the current behavioural data, experiment two did uncover that both speed and accuracy of participants responses were impaired when sad valence appeared during search. Faster and more accurate responses were associated with the presence of surprise, disgust, then happy valence. Level of arousal may have accounted for the emergence of valence modulation to behavioural performance. Whether this also influenced

the profile of ERP response between the t-f-s and t-f-r tasks will be clarified through the ERP findings.

3.4.2: *ERP findings*

3.4.2.1: *Ppc:* 76-114 ms

There was no evidence for increased strategic continuous suppression under the more challenging t-f-s, versus t-f-r condition as no main effect of task emerged. It had been hypothesised that increased Ppc laterality divergence may be seen for the current t-f-s, versus t-f-r condition because a previous study (Bretherton et al., 2017) found that Ppc laterality divergence was greater in response to high, compared to low task difficulty. An important difference between the task difficulty comparison in Bretherton et al's. (2017) paradigm and the current experiment two paradigm relates to the type of task difficulty in question. A letter target was discriminated from a more similar (high difficulty), or less similar (low difficulty) letter in Bretherton et al's. (2017) paradigm; thus perceptual difficulty was manipulated. In the current paradigm a face with high socio-motivational salience required suppression (difficult t-f-s condition), or selection (easy t-f-r condition); thus cognitive difficulty was manipulated. Lavie et al's. (2004) Load Theory was based on findings that increased perceptual difficulty improved distractor inhibition; whereas increased cognitive difficulty impaired distractor inhibition. A likely explanation for the absence of Ppc laterality modulation between the current t-f-s, versus t-f-r task is that increased strategic suppression could not be used to improve the chance of distractors being inhibited because the cognitive resources needed for this controlled response were unavailable due to the high cognitive demands of the current t-f-s task.

In-line with the findings of previous studies that suggest Ppc laterality divergence reflects low level stimulus driven processing that corresponds to sensory imbalances on visual search displays, or early identification of salient feature discontinuities (see Fontier-Gauthier et al., 2012; Leblanc et al., 2008; Luck & Hillyard, 1994a), the current t-f-s condition found enhanced Ppc laterality divergence when displays contained happy facial valence, compared with disgust and sad facial valence. The pattern of effects likely emerged because local feature discontinuities were

greater between neutral and happy face stimuli, when compared against neutral and disgust/sad face stimuli (see appendix D for face stimuli used in experiment two).

3.4.2.2: *Early attention:* 134-180 ms

Visual inspection of the ERP waveforms suggested there was increased attentional selection when the neutral face was a t-f-s, than a t-f-r; however the ANOVA revealed that early attentional capture by the lateral stimulus was not modulated by task or valence of the emotional face. The finding contrasts to the hypothesised effects. A profile in-line with saliency-driven processing was expected to emerge as increased attentional capture by emotional valence, versus neutral face inputs, irrespective of task; whereas a profile of response in line with controlled goal-driven processing would have been evidenced in the neutral t-f-r condition by an early P_D opposite the t-f-r, versus an N_T opposite emotional target items. In the t-f-s condition, controlled template-guided processing would have been evidenced by the presence of an N_T (target selection) opposite the neutral t-f-s, but with reduced laterality divergence when compared with the N_D (emotional distractor evoked capture) because of the high socio-emotional salience of the emotional faces. With respect to the next attention interval, distractor evoked capture by the emotional face would expectedly be suppressed, whereas neutral template selection would be maintained.

It is possible that with an increased sample size, template status (t-f-s, vs. t-f-r) and possibly socio-emotional salience would have significantly modulated the early selection response; however, increasing the sample may not have changed the pattern of results observed. A possible explanation for the 134-180ms interval results is that the high cognitive demands of experiment two may have reduced resources available for early controlled attentional suppression (see Lavie et al's., 2004 Load Theory). Diminished attentional control could plausibly result in attentional selection of the lateral stimulus irrespective of task. Alternatively, in contrast to experiment one, inter-stimulus competition may have been low in experiment two because the lateral face alone mapped onto ventral processing streams, while the midline face would have mapped onto dorsal areas; this could have accounted for early selection of the lateral face, irrespective of its task

relevance, or socio-motivational salience (see., Ro, Russell, & Lavie., 2001; Vuilleumier, 2000 for evidence of paradigm-driven change to inter-stimulus competition). Bretherton et al. (2017) also found that when perceptual demands were low (two item sparse array) the lateral face was selected despite it being irrelevant to the task. It should be said that the current finding of lateral face selection, irrespective of task would seem an evolutionarily beneficial response as faces communicate consequential social information such as threat or benefit and may therefore, be more resistant to early active suppression than other stimulus types.

3.4.2.3: *Late attention:* 230-260 ms

The profile of response for the previous interval depicted attentional selection of the lateral face irrespective of task or saliency factors. It was suggested that the finding was either due to decreased inter-stimulus competition because of the positioning of stimuli on the sparse array used in experiment two, resulting in a similar level of selection for all lateral face inputs. The finding may also have emerged because the high socio-motivational salience of the experiment two stimuli made them resistant to controlled goal-driven processing, at least during the early attention interval. Although suppression of early attentional capture was not revealed during the 134-180ms interval, participants were able to perform experiment two with above chance accuracy; therefore, some activation of attentional control networks would likely have occurred during late attention processing.

With respect to the lateral neutral face, the ERP wave-form for the 230-260ms interval appeared to depict a P_D opposite the t-f-r, versus an N_T opposite the t-f-s, however the direction of laterality divergence effects did not reach statistical significance. As discussed in the methods section, the sample size used for experiment two was smaller than originally intended due to greater than expected attrition. It is possible therefore, that with the data from more participants included, the visually identified contralaterality differences would have reached statistical significance. This would have confirmed late template-guided processing following early automatic selection of all lateral stimuli. A higher likelihood of finding evidence for controlled attention processing was expected for neutral face inputs because of the template status and relatively reduced socio-motivational salience associated with these compared with the emotional faces.

There was statistically significant laterality divergence (indicating attentional selection) when emotional faces were attended (midline t-f-r); which was not present (no significant laterality divergence) when emotional faces were ignored (midline t-f-s). Continued engagement with the highly salient emotional target face was expected during the 230-260ms late attention interval, as the findings of experiment one appeared in-line with early saliency-driven capture, followed by continued attentional engagement when the more salient face was also the target. Previous findings (Liesefeld et al., 2017) demonstrated that early attentional capture by a salient distractor was rectified so that during late attention processing, the less salient target received attentional selection. Thus, if a target with low salience can receive goal-driven attentional selection processing during late attention, then it is unsurprising that the current highly salient target would receive attentional selection processing during an equivalent late attention interval. During the current late attention interval the emotional target was the only stimulus type associated with significant laterality divergence. The neutral t-f-s did not receive statistically quantifiable attentional selection processing (laterality divergence was non-significant). This suggests that contributions from goal-driven and saliency-driven processing accounted for why laterality divergence was significant for the lateral emotional target and not for the neutral t-f-s.

The absence of statistically significant N_D laterality divergence opposite the emotional distractor on midline t-f-s trials may demonstrate that as hypothesised, there was reduced cognitive control due to increased cognitive load on the more difficult t-f-s block. Cognitive load would have increased when the less salient neutral template face required attentional selection. In-line with the findings of Lavie et al. (2004) this would have resulted in reduced ability to suppress attentional selection networks that responded to the emotional distractor on t-f-s trials. This may go some way to explaining why there was a non-significant N_D opposite the emotional distractor, rather than a P_D indicating controlled suppression of distractor evoked capture.

3.4.2.4: *Late sustained processing interval- SPCN:* 300-500 ms

Sustained contralaterality (SPCN) has been implicated in encoding and maintenance of stimulus representations in visual short term memory and working memory (VSTM and VWM; see Dell'Acqua et al., 2006; Jolicoeur et al., 2006; Klaver et al., 1999; Vogel & Machizawa, 2004).

A previous study (Jannati et al., 2013) found that SPCN contralaterality diverged for lateral targets, but not for lateral distractors, suggesting that goal-driven attentional selection may facilitate the encoding and maintenance of stimulus inputs in visual short term memory (VSTM). Holmes et al. (2009) reported enhanced SPCN contralaterality to emotional (angry and happy), as compared against neutral faces which occurred despite no task-related need to maintain facial valence in VSTM. This was interpreted as evidence that top-down template signals which normally work to facilitate maintenance of visual spatial attention toward goal-relevant stimuli (see Desimone & Duncan, 1995) were likely triggered in an obligatory fashion by emotion generated feedback loops (see Vogel & Machizawa, 2004; Pourtois et al., 2013). Thus, converging investigations appear to suggest that selective attention networks may modulate the profile of the SPCN component according to the emotional salience (Holmes et al., 2009) and task-relevance (Jannati et al., 2013) of stimulus inputs.

In a study by Feldmann-Wüstefeld and Vogel (2019) the CDA (contralateral delay activity) component, known to modulate according to visual working memory (VWM) demands and capacity (Vogel & Machizawa, 2004) was found to reflect the summed contributions of negative and positive sub-components. When to-be-memorised targets, versus to-be-ignored distractors were laterally presented the CDA (approx. 350-750 ms post-stimulus onset) indexed a respective contralateral positivity (P_D), versus contralateral negativity (N_T). The authors suggested that the classical CDA may reflect upward or downward regulation of stimulus features at the location of stimulus presentation to respectively enhance maintenance of, or prevent distractors interfering with to-be-remembered items in VWM.

The possibility that the classical SPCN component may also reflect the sum of positive and negative contributions was therefore, hypothesised because in the current template-guided

processing task, the prevention or enhancement of encoding and maintenance of face inputs would facilitate task performance. In light of Holmes et al's. (2009) findings it was further hypothesised that the increased socio-motivational status of emotional inputs could further modulate the profile of the SPCN.

The SPCN response for the current experiment revealed an SPD (sustained inhibition response) opposite the neutral t-f-r, versus an SNT (sustained selection response) opposite the neutral t-f-s. Similarly, on midline t-f-s trials there was an SPD to (sustained inhibition of) the lateral emotional distractor; whereas on midline t-f-r trials there was an SNT to (sustained selection of) the lateral emotional target. The direction of effects did not differ according to the socio-motivational salience of the lateral face. It was previously noted that accuracy in experiment two was above chance, so ERP evidence for controlled goal-driven processing was expected during the attention intervals, but little evidence for goal-directed processing was revealed during the previous processing stages. It seems that for experiment two encoding and maintenance of target and distractor inputs in VWM (as indexed by the SPCN) was respectively enhanced or prevented at the items location. The sequence of ERP response suggests that when cognitive load is high, task performance can be maintained through controlled goal-driven processing at the stage of VWM encoding and maintenance. This new evidence further shows that the classical SPCN may also reflect the sum of positive and negative contributions.

Finally, it is possible that if the template and non-template stimuli had been of comparable salience, then enhanced goal-driven processing for template-matching inputs would have been found. For the upcoming experiment three, angry valence will be the t-f-r or t-f-s. The same emotional faces (happy, sad, surprised, disgust) will appear as the other face on sparse displays. The aims of experiment three will be to clarify the angry template findings of experiment one and to investigate whether controlled attention processing will be enhanced for angry t-f-r and t-f-s inputs compared with the other emotion inputs. The final thesis discussion in chapter seven will compare angry and neutral template utility.

Chapter 4: Angry templates-for-rejection and selection

4.1: Introduction

The angry templates condition in experiment one of the current thesis uncovered faster reaction times when angry faces were t-f-s, versus t-f-r. Although the corresponding ERP profile of response appeared to show that the N2pc flipped between the bilaterally presented items, laterality divergence reached significance for none of the explored component intervals.

It was considered that laterality divergence may have been absent because the face pairs presented for the angry template condition in experiment one comprised stimuli that were both highly emotionally salient. As a consequence, attentional control may have been reduced, and attention may have been repeatedly pulled between the adjacent emotional faces. Rapid and repeated attentional switching between the competing emotionally salient stimuli may have driven only marginal attentional lateralisation that may not have been statistically distinguishable because of the summed nature of ERPs recorded to the previous bilateral array.

Previous research has shown that facial expressions of emotion and in particular, angry emotion, automatically evoke attentional prioritisation (e.g., Eimer & Holmes, 2003; Fox et al., 2001; Fox et al., 2002; Holmes et al., 2009; Holmes et al., 2014; Ohman et al., 2001; Pourtois et al., 2013), and facial expressions that may cue or depict potential threat have been evidenced to capture and hold attentional focus (e.g., Fox et al., 2001; Fox et al., 2002). Separately, it has been proposed that happy valence may benefit from enhanced processing due to its associated value with reward, initiation and maintenance of social interactions and positive bonds (e.g., Calvo et al., 2010; Tomkins, 1962). There may also be distinct neural systems responsible for processing specific facial emotions; for instance, the amygdala (a limbic structure involved in rapid threat detection and response) is specialised for processing facial expressions of fear (Pourtois et al., 2013); while processing the expression of disgust has been linked to the insula (separates the frontal and parietal lobes from the temporal lobe and seems to be emotion sensitive with feedforward subcortical mechanisms that may generate top-down control over ventral attention processing), and basal ganglia (a mid-brain structure involved in emotion and movement), (see Adolphs, 2002). It is possible that stimulus-driven inputs from mid-brain regulators activated in response to both the angry template and the other emotion (where “other emotion” refers to sad, surprised, disgusted, or happy valence). This may have been at

least partially responsible for the failure of any one stimulus to receive controlled attentional processing.

It was previously mentioned that the high socio-motivational salience of the faces presented in the angry template condition of experiment one may have resulted in rapid and repeated attentional pull. It is also possible that perceptual similarities between the adjacently presented faces may have contributed to increased task difficultly in the angry template condition (see appendix D for stimuli used in the angry template condition). It has been shown through previous research findings (Vuilleumier et al., 2001) that rapid emotion-driven subcortical processing did not improve participants ability to overtly identify facial expressions that were not task relevant. Therefore, even if in experiment one, the angry template and other emotion received rapid subcortical response, the task itself, which was to identify the sex of the angry (t-f-s), or non-angry (t-f-r) face, may nonetheless have been very challenging when face pairs were perceptually similar. Local feature similarities between angry and disgusted, or sad facial expressions may have been greater resulting in increased perceptual difficulty because these faces all presented with mouth downturned. In contrast, happy facial expression appeared with mouth upturned and surprised facial expression appeared with eyes wide which would have contrasted to narrow eyes on the angry faces, resulting in comparatively reduce perceptual difficulty. It is therefore, possible that perceptual load may have differed according to the extent of local feature similarities between face pairs. Tottenham et al. (2009) proposed that local feature similarities likely accounted for their finding of higher facial expression mislabeling between some expressions in the Nimstim Face Set; of which a sub-set were used for experiments one to three of the current thesis. This issue was not addressed in experiment one because template valence (angry vs. neutral) had been included as an experiment factor and as such, trial numbers were too low to additionally investigate experiment interactions involving valence of the other emotion.

To resolve the question of whether specific emotion combinations were harder than others to distinguish, and to isolate attentional processing associated with the angry template, versus other emotion, the current experiment three will include valence of the other emotion as an experiment factor, and will use a sparse display paradigm similar to that originally employed by Hickey et al.

2009) and analogous to that used for experiment two.

In a recent review Gaspelin and Luck (2019) used the terms *proactive suppression* and *reactive suppression* to extend Sawaki and Luck's (2010) previously proposed Signal Suppression Hypothesis of attentional capture (SSH). The SSH proposes that non-target stimuli with high physical salience elicit an 'attend-to-me' priority signal that can be actively suppressed to avoid attentional capture by the salient, but task-irrelevant feature-matching item. Investigations carried out to test the predictions of the SSH reported conflicting evidence with respect to when and how salient non-targets may be actively suppressed (e.g., Cunningham & Egeth 2016; Gaspelin & Luck, 2018; Moher & Egeth, 2012; Sawaki et al., 2012; Sawaki & Luck, 2010). Subsequently, Gaspelin and Luck (2019) posited an extension to the SSH, that learned non-target features can be used to reduce the neuronal gain response (see Desimone & Duncan, 1995) for specific feature values before stimulus onset in order to effectively reduce processing of feature-matching inputs. In particular, Gaspelin and Luck (2019) suggest that when a salient non-target feature can, versus cannot be reliably predicted, its saliency signal is respectively, *proactively suppressed* (suppressed without the need for prior selection), as opposed to being *reactively suppressed* (is selected prior to being suppressed). Gaspelin and Luck's (2019) extension to the SSH related specifically to the findings of singleton search paradigms. Little research that was known of at the time of writing has been done looking specifically at template guided attentional control with respect to stimuli that have high socio-motivational salience. Valence templates may not be subject to the same controlled processing considering their ability to evoke rapid sub-cortical response.

Recently, Bretherton et al. (2017) employed a Hickey style sparse search design to investigate mechanisms of suppression for stimuli with socio-emotional significance. Through isolation of the lateralised ERP response to the evoking stimulus, the authors revealed that when face stimuli were distractors, they evoked attentional capture prior to suppression. In contrast, non-face stimuli could be suppressed without evoking initial attentional capture. When perceptual difficulty of their target discrimination task increased, this early capture response was attenuated for neutral, but not angry facial valence. Bretherton et al's. (2017) findings suggest facial stimuli that depict threat evoke automatic stimulus-driven processing irrespective of perceptual load (also see Eastwood et al., 2001; Fenske & Eastwood, 2003; Fox et al., 2001; Fox et al., 2002; Holmes et al., 2009; Ohman et

al., 2001; Vuilleumier & Schwartz, 2001a, 2001b for further supportive evidence).

A further finding with respect to the Bretherton et al. (2017) investigation was that behaviour was unaffected by facial expression, suggesting that reactive suppression following early attentional capture may have allowed task performance to be maintained between experiment conditions. Notably, experiment two of the current thesis observed that behavioural responses were not significantly modulated according to whether the neutral face was a t-f-r or t-f-s, but late VWM processing was modulated by task-goals as uploading and maintenance of the visual representation of neutral t-f-r versus t-f-s was respectively suppressed (sustained contralateral positivity), versus enhanced (sustained contralateral negativity). This direction of sustained processing was also revealed when the lateral emotional face was a distractor (midline t-f-s trials), versus a target (midline t-f-r trials). Taken together, the findings of experiment two and of Bretherton et al. (2017) suggest that despite early attentional capture by stimuli with high socio-motivational salience, performance can be maintained through subsequent controlled processing.

The findings of experiment two strongly supported that stimuli with high socio-motivational salience may not be subject to proactive suppression because of emotion sensitive sub-cortical circuitry influences on ventral processing leading to early attentional capture. Evidence for goal-driven controlled processing did not emerge during the late attention interval in experiment two. Instead, task performance seemed to be maintained by suppressing or enhancing uploading and maintenance of the visual representation of search items in VWM. The findings of experiment one appeared to demonstrate that controlled processing was better during the neutral template (where laterality divergence was significant), than angry template (wherein there was no significant laterality divergence) tasks. This corresponded to overall faster and more accurate responses for the neutral, versus angry template conditions. Thus, for the current experiment three it is expected that there will be more stimulus-driven, than goal-driven processing evidenced in the ERP profile of response.

A sparse search array analogous to that employed for experiment two, was chosen for the current experiment three. One face appeared above, or below and the other face to the left, or right with respect to a central fixation cross. Of eight possible individuals, one would appear with angry facial expression (angry template), the other with either disgust, happy, sad, or surprised facial

expression (other emotion stimulus). The design was chosen to allow isolation of attentional processing elicited in response to the lateral angry template, or lateral emotional stimulus.

For experiment three it was hypothesised that:

Behavioural responses:

Previous findings show prioritisation of threatening, over non-threatening inputs (e.g., Pourtois et al., 2013). The angry template findings of experiment one support prioritisation of threat as faster and more accurate behavioural performance was associated with angry t-f-s, versus t-f-r blocks, suggesting it was easier to attend to, than ignore angry valence. It is therefore, expected that:

a) faster and more accurate responses will be associated with the angry t-f-s, versus t-f-r blocks.

Early attention (148-188ms) and late attention (224-264ms) intervals:

Because angry expression has been shown to capture and hold attention more than other expressions it is expected that:

b) there will be enhanced selection specific laterality divergence (enhanced contralateral negativity) for angry template-matching inputs, versus other emotion inputs during the early and late attention intervals irrespective of task-goals.

SPCN (280-500ms) interval:

As the previous experiment two found evidence of controlled processing during the late sustained processing (SPCN) interval, it is possible that experience with the angry template will allow some controlled processing during this late interval in line with task goals, otherwise response accuracy may not be maintained above chance level. It is expected that during the SPCN interval:

c) there will be a sustained contralateral negativity (SN_T) opposite angry t-f-s inputs, versus a sustained contralateral positivity (SP_D) opposite angry t-f-r inputs. The difference will be significantly more pronounced in comparison to the sustained contralateral negativity (SN_T) versus positivity (SN_D) opposite emotional target and distractors inputs on midline t-f-r and t-f-s trials respectively.

Ppc (70-128ms) interval:

Experiment two did not reveal modulation of Ppc laterality divergence according to differences in task difficulty between the t-f-s and t-f-r experiment blocks. In the experiment two t-f-s condition enhanced Ppc laterality divergence emerged when displays contained happy facial valence, versus disgust and sad facial valence which likely reflected that there were greater local feature discontinuities between neutral and happy face stimuli, when compared against neutral and disgust/sad face stimuli (see appendix D for face stimuli used in experiment two). The data supported previous findings that suggest the Ppc index's early identification of salient feature discontinuities (see Fontier-Gauthier et al., 2012; Leblanc et al., 2008; Luck & Hillyard, 1994a). It was suggested in the current introduction that there may have been greater perceptual similarity between angry and sad/disgust inputs than between angry and happy/surprised inputs. It is therefore expected that:

d) Ppc laterality divergence will be enhanced when angry template displays contain happy and surprised emotional expression, as compared to sad and disgust emotional expression.

4.2: Methods

4.2.1: *Participants*

A statistical power analysis was performed in GPower 3.1.9.4 for sample size estimation. As with experiment two, experiment three was a 2 x 2 x 2 x 4 x 5 repeated measures ANOVA; therefore, the same values that were used for the previous experiment two power analysis were also used for experiment three. The previously entered effect size and partial eta squared values (F = 3.25, ηp^2 = .17) were entered with the more conservative required alpha and power values (p < .01, power = .85). The projected sample size was N = 20. As with the data collection for experiment two, the data for experiment three was collected outside term time. Because of this participant recruitment was challenging.

A sample of twenty healthy volunteers were recruited and all gave informed consent before beginning the experiment. Two participants were excluded due to low accepted trial numbers (> 25% rejected trials) post artefact rejection for horizontal and vertical eye movements. One participant was excluded due to a mean Acc score below the 65% criterion for inclusion. The seventeen remaining participants (10 female), were aged eighteen to thirty-one (mean ± SD age = 20.18 ± 3.25 years).All participants (14 right-handed), reported normal or corrected-to-normal vision. The experiment was performed in compliance with The University of Roehampton ethical and research guidelines and was approved by the University ethics committee.

4.2.2: *Stimuli and Apparatus*

Simultaneously presented face pairs (greyscale stimuli taken from the NimStim Set of Facial Expressions (available at http://www.macbrain.org/faces/) Tottenham et al., 2009) comprised two (one above or below fixation, the other to the left or right of fixation) of eight possible face IDs, with one photograph portraying an angry expression (select template/inhibit template) and the other photograph portraying a sad, surprise, disgust, or happy expression at equal probability. A total of 768 experiment trials (384 per block) were selected in random order from 768 different ID x emotion x midline position x lateral position x template position x sex combinations, reset at the start of experiment blocks for each participant. Sex of the target and distractor stimuli (female-female/male-male/female-male) were presented at equiprobable left or right, above or below

fixation locations. Participants completed 32 practice trials (16 select / 16 inhibit) with accuracy and response time feedback. The practice trials could be repeated to achieve a minimum of 70% accuracy before beginning the main experiment. The face stimuli and stimulus dimensions, including distance from central fixation, were adapted from Holmes et al. (2009); for the purpose of the practice and main experiment trials of the current experiment, faces were cropped in an oval shape (2.65cm wide × 3.25cm high) to remove hair or clothing and subtended 3.99° x 4.3° of visual angle. To isolate target versus distractor contributions to the observed ERP component and to reduce trial numbers and therefore, experiment duration and participant fatigue, stimulus displays were adapted from the six visual angle positions used by Hickey et al. (2008) (60°, 120°, 240°, 300°), wherein horizontal stimuli appeared marginally above or below the horizontal midline, to four visual angle positions (90°, 180°, 270°, 360°), so that one face appeared directly above or below fixation, whilst the second face appeared directly to the left or right with respect to fixation. Analogous to Holmes et al. (2009), the centres of the faces were presented 25 mm from the centre of a grey (184 cd/m²) central fixation cross (6mm x 6mm) against a dark grey (9 cd/m²) background. The faces within each face pair were equated for mean luminance and root mean square (RMS) contrast energy. Mean luminance energy was calculated for each face stimulus, then equated across all face stimuli. Total RMS energy for each luminance equated face was then calculated, and the luminance value at each pixel from each face was divided by that value (using standard routines in Matlab 6), resulting in a mean luminance value of 7.83 cd/m2, and Michelson contrast of .934.

Participants were seated in a dark cubicle, 55 cm from a 17-in. ViewSonic G220f computer screen with a refresh rate of 75Hz, connected to a Dell precision Pentium IV computer. E-Prime Psychology Software 2.0 (Schneider et al., 2002) was used for stimulus presentation and response collection. Responses were indicated via a purpose built response box.

4.2.3: *Procedure*

Experiment trials (see Figure 1 for example trial sequence) started with a central fixation cross for 500ms, followed by a face pair (see Stimuli and Apparatus for face pair configurations) for 600ms. Responses were collected from the start of face pair onset to the end of a proceeding blank screen inter stimulus interval (ITI) for 1500 or 1800 ms at random to prevent habituation.

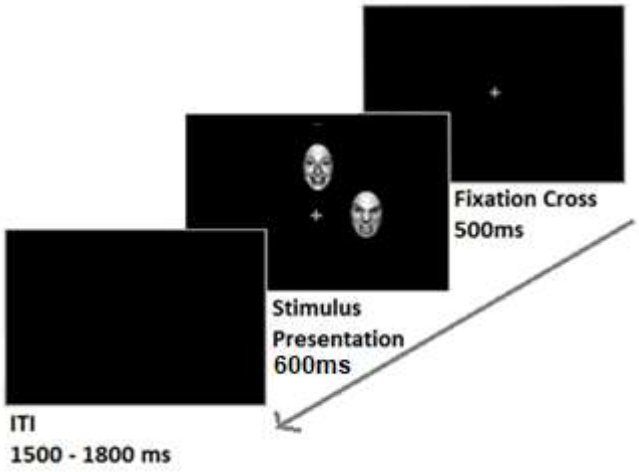


Figure 4.1 Example of select lateral template with midline happy valence distractor. Trial sequence with timings depicted. *Stimuli not to scale.*

The participants were randomly allocated to receive the select template block prior to the inhibit template block, or vice versa. An instruction screen directed participants to indicate as quickly and accurately as possible, the sex of the angry face (select template block), or the non-angry face (inhibit template block). Sex of the target face was indicated using the index and middle finger of the dominant hand and buttons one and two (counterbalanced across participants) on a purpose built response box. Approximately every 68 seconds participants received an on-screen instruction to take a short break and press the space-bar when ready to continue.

4.2.4: *EEG Data Acquisition*

EEG was recorded from 32 Ag-AgCl electrodes (Fp1, Fp2, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T8, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, O1, Oz, O2, PO7, PO8, PO9 and PO10 (according to the 10-20 system)), referenced on-line to the vertex and then re-referenced off-line to the average of the left/right mastoids. Horizontal EOG (HEOG) was recorded bipolarly from the outer canthi of both eyes and vertical EOG (VEOG) was recorded bipolarly, above the brow and below the left eye. See Figure 3 for electrode layout. All electrode impedances were kept below 5 kΩ; EEG and EOG were digitised with a 500 Hz sampling rate. The EEG was

filtered online at d.c. to 100 Hz with vertex (CZ) as the online reference. Following EEG recording, data were digitally filtered offline with a bandpass of .3 Hz (24 db/oct) to 30 Hz (24 db/oct; zero-phase shift) using Neuroscan software (version 4.5). EEG and HEOG were then epoched into 600ms intervals, from 100ms before (pre-stimulus baseline) to 500ms after face pair onset. Trials with lateral or vertical eye movements (HEOG/ VEOG exceeding ± 40 μV and ± 80 μV, respectively) and trials with eyeblinks (Fp1/Fp2 exceeding ± 60 μV), or other artifacts (voltage at any electrode exceeding ± 100 μV) measured in each epoch were excluded from the analysis. Epochs were then re-referenced to the average of A1 and A2 ear lobe electrode locations.

Separate averages were computed for all combinations of task (select template, inhibit template) x emotion (disgust, happy, sad, surprised) x template position (lateral, midline). Contralateral ERPs were the average of the left (P7) and right (P8) hemisphere electrodes for lateral stimuli presented to the right and left visual fields, respectively. Ipsilateral ERPs were the average of the left (P7) and right (P8) hemisphere electrodes for lateral stimuli presented to the left and right visual field, respectively; therefore, contralateral versus ipsilateral ERPs were the opposite, versus same-sided hemisphere, to the lateral stimulus. Electrodes P7 and P8 were selected for analysis because contralaterality effects were maximal at those sites.

4.2.5: *Component time-window selection*

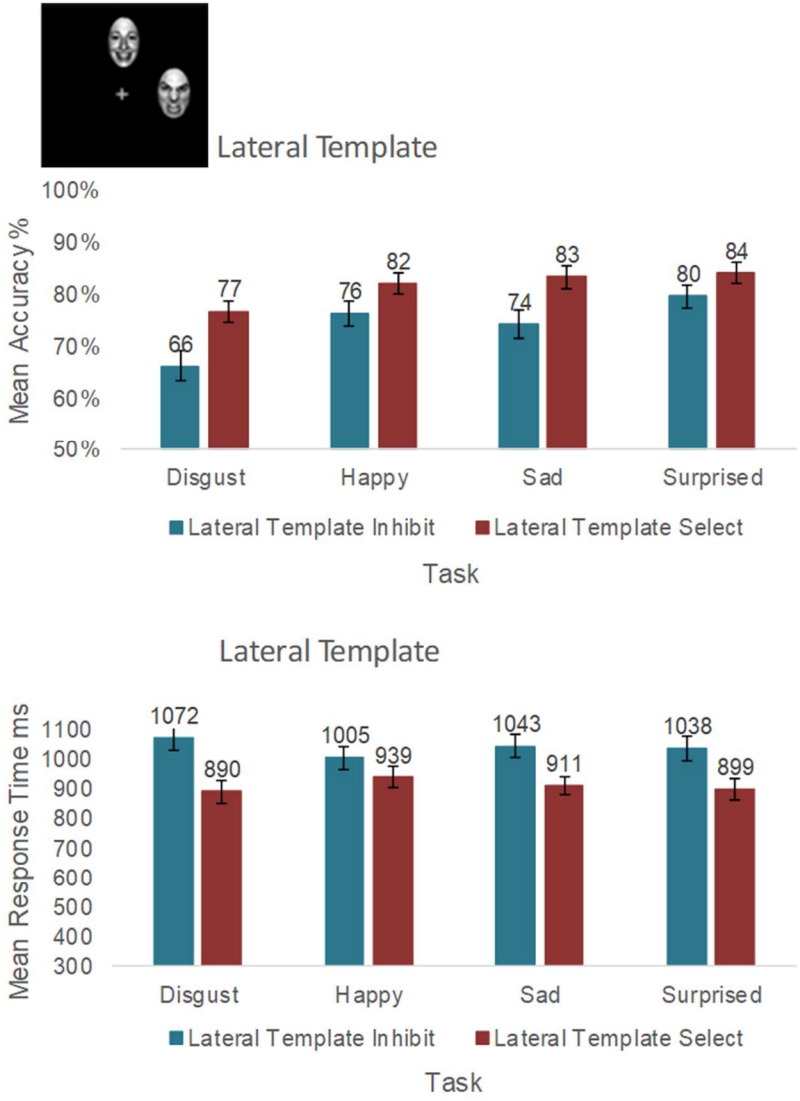
Visual inspection of the ERP waveforms, combined with previous research on contralateral components such as the Ppc, early N2pc, late N2pc and SPCN (e.g., Bretherton et al., 2017; Fontier-Gauthier et al., 2012; Grubert & Eimer, 2016; Hickey et al., 2009; Holmes et al., 2009; Holmes et al., 2013; Jannati et al., 2013; Woodman & Luck, 2003), resulted in identification of five ERP component time-windows that best represented the modulations of contralaterality effects (i.e., in attention processing) elicited by the current paradigm. Component time-windows were as follows: Ppc (70-128ms), early attention (148-188ms), late attention (224-264ms) and sustained processing SPCN (280-500).

4.3: Results

4.3.1: *Behavioural Results*

Non-responses and trials with response times (RTs) below 300ms were discarded; the subsequent mean and standard error of RTs for the sample was: M = 971.91 and SEM = 2.76, respectively. Mean percentage accurate responses (Acc) and mean correct response times (RTs), for each participant, were entered into a repeated measures analysis of variance (ANOVA), with the factors: task (select vs. inhibit), emotion (disgust vs. happy vs. sad vs. surprised), and template position (lateral vs. midline). Note that for the select conditions, participants were given an angry template-for-selection; no distractor valence information was available. For the inhibit conditions, participants were given an angry template-for-rejection; no target valence information was available. Where post-hoc t-tests were carried out, the Bonferroni correction for multiple testing was applied with adjusted alpha level (.05/number of tests). Where Mauchley's test for the assumption of sphericity was violated, Greenhouse-Geisser corrected values were reported with degrees of freedom taken from sphericity assumed.

Figure 4.3 (next page) depicts the task-driven: inhibit (blue bars), versus select (red bars), Acc (top panel) and RT (bottom panel) means, for trials with lateral templates (left side) and midline templates (right side). Pairs of bars correspond to inhibit versus select template conditions, for stimulus displays with emotion valence: disgust, happy, sad and surprised, respectively.


Lateral Template
100%
90%
80%
70%
60%
50%
Mean Accuracy %
66
77
76
82
74
83
80
84
Disgust
Happy
Sad
Surprised
Lateral Template Inhibit
Lateral Template Select
Task
Lateral Template
Mean Response Time ms
1100
1000
900
800
700
600
500
400
300
1072
890
1005
939
1043
911
1038
899
Disgust
Happy
Sad
Surprised
Lateral Template Inhibit
Lateral Template Select
Task

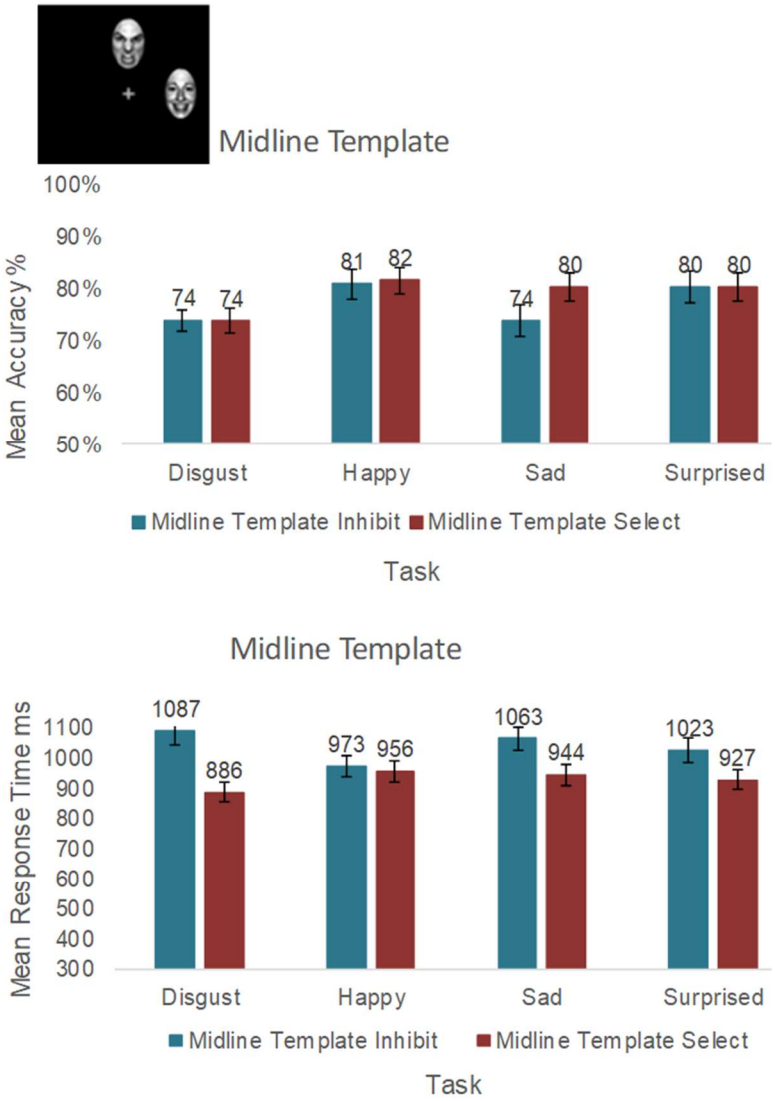

Midline Template
100%
90%
80%
70%
60%
50%
Mean Accuracy %
74
74
81
82
74
80
80
80
Disgust
Happy
Sad
Surprised
Midline Template Inhibit
Midline Template Select
Task
Midline Template
Mean Response Time ms
1100
1000
900
800
700
600
500
400
300
1087
886
973
956
1063
944
1023
927
Disgust
Happy
Sad
Surprised
Midline Template Inhibit
Midline Template Select
Task

Figure 4.2

4.3.1.1: *Accuracy*

Task significantly modulated Acc*, F(*1,16) = 29.2, $p < .001$, $\eta p^2 = .65$, as template inhibition was associated with lower Acc (*M* = 75.64%, *SEM* = 2.03), than template selection (*M* = 80.26%, *SEM* = 1.83). Furthermore, emotion significantly modulated Acc*, F(*3,48) = 18.3, $p < .001$, $\eta p^2 = .53$. Displays that contained disgust valence drew the lowest Acc scores (*M* = 72.65%, *SEM* = 1.69) followed by displays with sad (*M* = 77.9%, *SEM* = 2.23), happy (*M* = 80.19%, *SEM* = 2.08), then surprised valence (*M* = 81.05%, *SEM* = 2.1). No further main effects were observed (all $p \geq .05$).

A two way task x template position interaction*, F(*1,16) = 6.23, $p = .024$, $\eta p^2 = .28$, was followed up (Bonferroni adjusted alpha .0125 per test (.05/4)); revealed was lower Acc when lateral templates were rejected (*M* = 74.06%, *SEM* = 2.17), versus selected (*M* = 81.5%, *SEM* = 1.75), *t*(16) = -4.61, $p < .001$. The direction of effects was also observed when midline templates were rejected (*M* = 77.22%, *SEM* = 2.21), versus selected (*M* = 79.02%, *SEM* = 2.14), although the difference was non-significant, *t*(16) = -1.51, $p = .15$, *ns*.

The no further interaction effects were observed (all $p \geq .05$).

4.3.1.2: *Response Times*

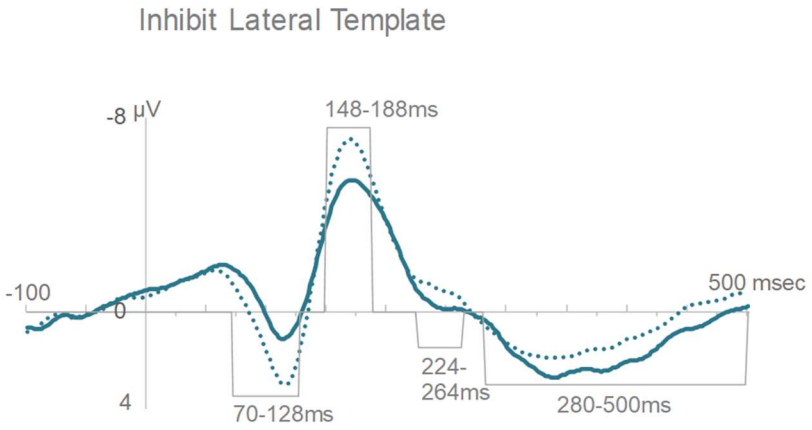
A main effect of task*, F(*1,16) = 30.67, $p < .001$, $\eta p^2 = .66$, was in line with significantly slower responses when templates were inhibited (*M* = 1037.91ms, *SEM* = 37.91), versus selected (*M* = 919ms, *SEM* = 31.99).

A highly significant two-way task x emotion interaction*, F(*3,48) = 23.13, $p < .001$, $\eta p^2 = .59$, was unpacked through post-hoc t-tests with Bonferroni adjusted alpha .0125 per test (.05/4). Slower responses were observed on inhibit, versus select template trials for disgust (respective means of: *M* = 1079.11ms, *SEM* = 40.87 and *M* = 888.17ms, *SEM* = 33.41, *t*(16) = 7.63, $p < .001$), sad (respective means of: *M* = 1053.17ms, *SEM* = 39.05 and *M* = 927.41ms, *SEM* = 32.81, *t*(16) = 5.29, $p < .001$) and surprised valence displays (respective means of: *M* = 1030.16ms, *SEM* = 39.92 and *M* = 913.27ms, *SEM* = 32.01, *t*(16) = 4.9, $p < .001$). The direction of effects was observed, though was non-significant when displays contained happy valence (respective means of: *M* = 989.2ms, *SEM* = 36.35 and *M* = 947.14ms, *SEM* = 33.04, *t*(16) = 1.77, $p > .0125$).

No further main effects or interaction effects were revealed (all $p \geq .05$).

4.3.2: *Electrophysiological Results*

Incorrect responses, non-responses and RTs below 300ms, were not included in the ANOVA of mean ERP amplitudes. The left side of figures 4.4 and 4.5 show ERPs contralateral (dotted lines) and ipsilateral (solid lines) to the location of the lateral stimulus, observed at lateral parietal-occipital electrode sites P7 and P8. Red lines and blue lines indicate where the lateral stimulus was selected, or inhibited, respectively. The bottom right of figures 4.4/4.5 show the contralateral minus ipsilateral difference waves that correspond to the lateral template (figure 4.4), and to the lateral emotion stimulus on midline template trials (figure 4.5). Indicated on each graph, are the component intervals selected for analysis: Ppc (70-128ms), early attention (148-188ms), late attention (224-264ms) and SPCN (280-500). Example stimulus displays and the task instructions that participants' received, appear at the top right of figures 4.4/4.5.



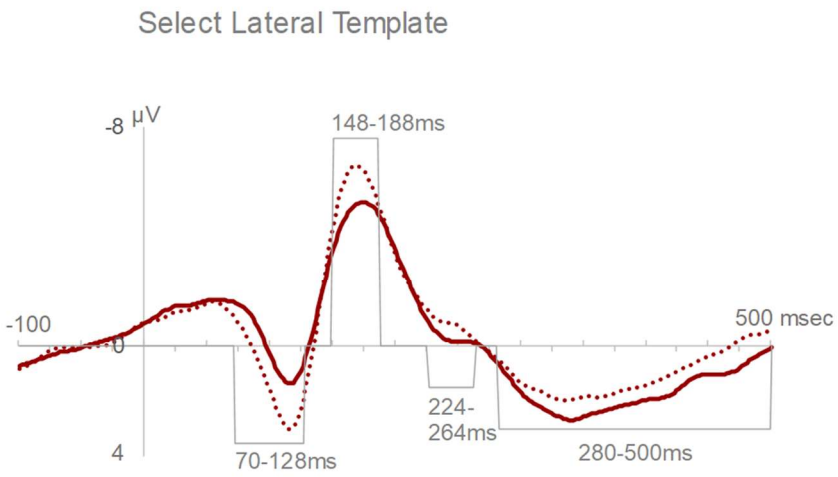
Task Instruction:

Select Template Instruction: 'Report the sex of the angry face'
Inhibit Template Instruction: 'Report the sex of the non-angry face'

Example of Lateral Template Stimuls Array:

Contralateral to lateral template- solid lines

Ipsilateral to lateral template- dashed lines



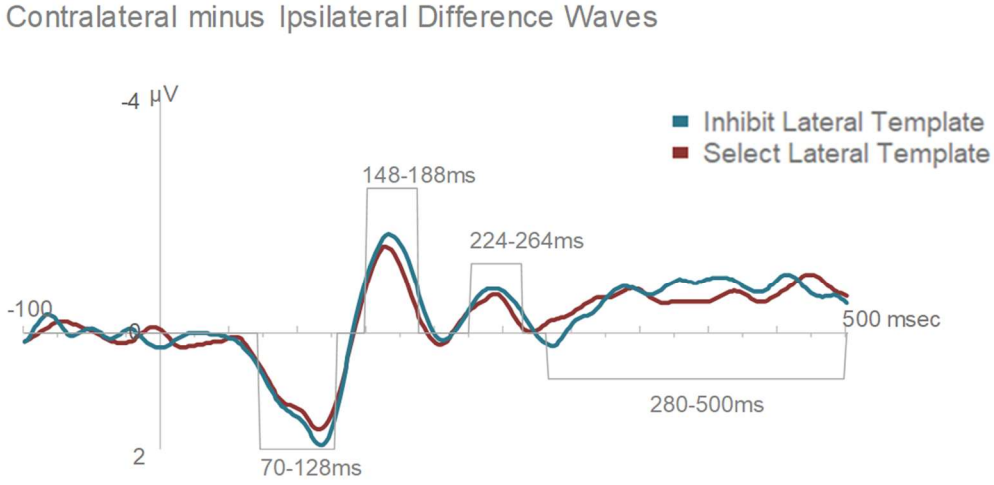
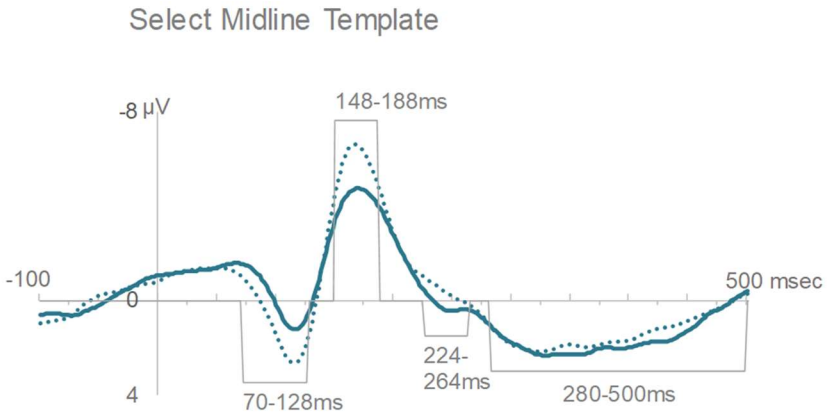


Figure 4.3



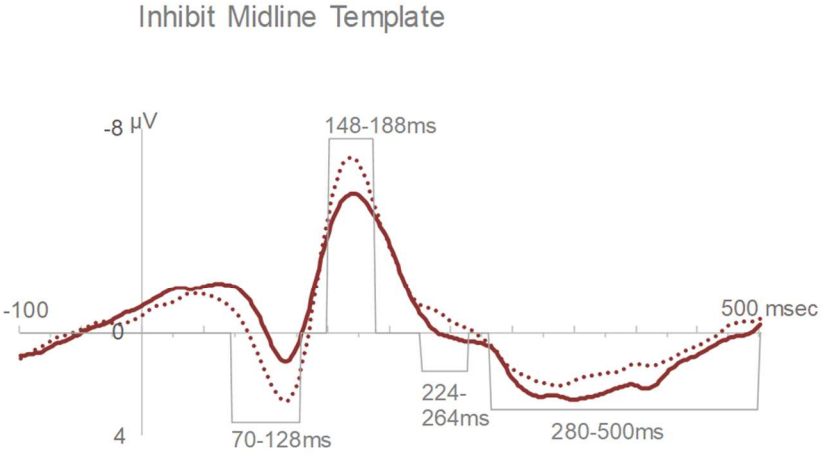
Task Instruction:

Select Template Instruction: 'Report the sex of the angry face'
Inhibit Template Instruction: 'Report the sex of the non-angry face'

Example of Midline Template Stimuls Array:

Contralateral to lateral stimulus- solid lines

Ipsilateral to lateral stimulus- dashed lines



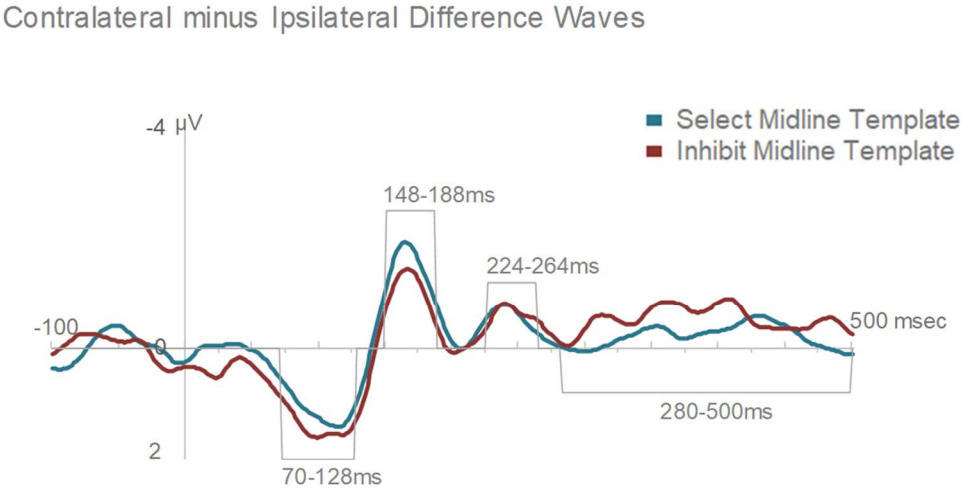


Figure 4.4

4.3.2.1: *ANOVA: all conditions*

Mean ERP amplitudes were entered into a 4 x 4 x 2 x 2 x 2 repeated measures ANOVA with the factors: component (intervals were: 70-128, 148-188, 224-264, 280-500 ms), emotion (disgust, happy, sad, surprised), laterality (contralateral vs. ipsilateral), template position (lateral vs. midline), and task (inhibit vs. select). See experiment methods (*ERP Components*) for details regarding time-window selection and functional interpretation. Where Mauchley's test for the assumption of sphericity was violated, Greenhouse-Geisser corrected values were reported with degrees of freedom taken from sphericity assumed. Where post-hoc t-tests were carried out, the Bonferroni correction for adjusted alpha level (.05/number of tests) was applied.

The main effect of laterality was significant, $F(1,16) = 5.1$, $p = .038$, $\eta p^2 = .24$, as mean amplitudes were significantly more negative at contralateral ($M = -1.09\ \mu V$, $SEM = .45$), versus ipsilateral ($M = -.84\ \mu V$, $SEM = .44$) electrode locations. The main effect of component was confirmed, $F(3,48) = 39.21$, $p < .001$, $\eta p^2 = .71$, as mean ERP amplitudes recorded during the post-stimulus intervals: 70-128ms, 148-188ms, 224-264ms and 280-500ms were: $M = .52\ \mu V$, $SEM = .31$, $M = -5.32\ \mu V$, $SEM = .73$, $M = -.39\ \mu V$, $SEM = .72$ and $M = 1.32\ \mu V$, $SEM = .55$, respectively. The main effects of laterality, task, template position, and emotion were non-significant (all $p \geq .05$).

There was a highly significant two way component x laterality interaction, $F(3,48) = 19.04$, $p < .001$, $\eta p^2 = .54$, and a further two-way component x template position interaction that reached significance, $F(3,48) = 2.87$, $p = .046$, $\eta p^2 = .15$. No further interaction effects were revealed (all $p \geq .05$).

The ANOVA of all conditions confirmed that the component intervals of interest elicited statistically different ERP response profiles and there was a highly significant two-way component x laterality interaction. In order to fully explore the hypotheses for experiment three the factors: laterality, task, template position, and emotion, were submitted to separate ANOVAs for each component (intervals were: 70-128, 148-188, 224-264, and 280-500 ms). Where the factor laterality reached significance, a further ANOVA for that time-window was executed with task, template

position, and emotion submitted as factors. The contralateral minus ipsilateral amplitude difference score became the dependent variable and represented the lateral stimulus elicited relative difference, from here on termed the contralaterality effect. The dependent variable change allowed laterality to be removed as a factor, thereby simplifying subsequent analyses.

4.3.2.1.1: *Ppc:* 70-128 ms

The main effect of laterality was highly significant*, F(*1,16) = 42.84, $p < .001$, $\eta p^2 = .73$, as mean amplitudes contralateral and ipsilateral to the lateral stimulus were *M* = 1.16 *μ*V, *SEM* = .33 and *M* = -.13 *μ*V, *SEM* = .33, respectively. The contralateral minus ipsilateral difference scores were therefore, entered into a three-way AVOVA with the factors: task, template position, and emotion.

There was no main effect of template position, or emotion (both $F \leq 1$) and the main effect of task failed to reach significance ($p > .05$).

4.3.2.1.2: *Early attention interval:* 148-188 ms

The main effect of laterality was highly significant ($F(1,16) = 18.75$, $p = .001$, $\eta p^2 = .54$), as mean amplitudes contralateral and ipsilateral to the lateral stimulus were *M* = -5.93 *μ*V, *SEM* = .81 and *M* = -4.71 *μ*V, *SEM* = .66, respectively. The contralateral minus ipsilateral difference scores were therefore, entered into a three-way AVOVA with the factors: task, template position, and emotion.

No main effects were revealed for the factors: task, template position (both $F \leq 1$), or emotion ($p > .05$) and no interaction effects were observed during the 148-188ms interval (all $p \geq .05$).

4.3.2.1.3: *Late attention interval:* 224-264 ms

The main effect of laterality was non-significant, F (1,16) = 3.09, p > .05, ηp² = .16, and no attention related interaction effects were revealed (all p≥.05).

4.3.2.1.4: *Late sustained processing interval:* 280-500 ms

The main effect of laterality was highly significant, F (1,16) = 27.2, p < .001, ηp² = .63, as mean amplitudes contralateral and ipsilateral to the lateral stimulus were M = 1.07 μV, SEM = .55 and M = 1.57 μV, SEM = .56, respectively. The contralateral minus ipsilateral difference scores were therefore, entered into a three-way AVOVA, with the factors: task, template position, and emotion.

The main effects of task and emotion were non-significant (both p≥.05); however, there was a main effect of template position, F (1,16) = 5.88, p = .03, ηp² = .27, as the contralateral negativity response was significantly enhanced when the lateral stimulus was a template, versus non-template face (respective means of: M = -.64 μV, SEM = .11 and M = -.37 μV, SEM = .11).

No interaction effects were revealed for the 280-500 ms interval (all p≥.05).

4.3.3: *Results Summaries*

4.3.3.1: ***Behavioural Results Summary***

4.3.3.1.1: *Accuracy*

Higher accuracy was observed on t-f-s, compared with t-f-r trials. Overall, accuracy was most impaired when displays contained disgust valence, with incremental improvements according to displays with sad, happy, then surprised valence.

4.3.3.1.2: *Response Times*

Response times were slower when templates were inhibited, versus selected. This task-driven difference was significant when emotional expression of the non-template face was sad, surprised and disgusted, but not happy.

4.3.3.2: ***Electrophysiological Results Summary***

4.3.3.2.1: *Ppc:* 70-128 ms

There was significant laterality divergence in response to the lateral stimulus. This was not modulated by task, template-position, or emotion.

4.3.3.2.2: *Early attention interval:* 148-188 ms

A contralateral negativity indicating attentional selection was observed in response to the lateral stimulus, suggesting that the representation of the lateral stimulus was enhanced irrespective of task or stimulus factors.

4.3.3.2.3: *Late attention interval:* 224-264 ms

No discernible laterality divergence was revealed during the post-stimulus interval: 224-264 ms.

4.3.3.2.4: *Late sustained processing interval::* 280-500 ms

There was an enhanced SPCN indicating sustained selection when the lateral stimulus was a template, versus non-template face. In contrast to the previous neutral templates experiment of the thesis, neither the direction, nor the magnitude of the SPCN component response differed according to task or emotional expression of the non-template face .

4.3: Discussion

Experiment one of the current thesis found faster reaction times when angry faces were t-f-s, versus t-f-r. The ERP profile visibly showed that N2pc contralaterality switched repeatedly between the bilaterally presented items, though no significant contralaterality divergence was revealed.

It was considered that absent laterality divergence may have occurred because all stimuli in the angry template condition had high socio-motivational salience. As a consequence, attentional control may have been reduced, and competition for the allocation of attention may have been repeatedly pulled between the bilaterally presented faces in a bottom-up stimulus-driven fashion. Rapid and repeated attentional switching between the competing and perceptually similar emotionally salient stimuli may have produced only marginal attentional lateralisation that may not have been statistically distinguishable because of the summed nature of ERPs recorded in experiment one.

Experiment three employed a sparse array paradigm in which the ERP response could be isolated with respect to the evoking stimulus. This was done by presenting only one stimulus laterally (to the left or right of fixation); the other stimulus would appear on the vertical midline (directly above or below the central fixation cross). Analogous to experiment two of the current thesis, a sparse display similar to that employed by Hickey et al. (2009) was used to allow statistical distinction between the ERP response evoked by each of the competing emotionally salient stimuli. It was expected that, if the current experiment three findings were similar to experiment one, such that t-f-s versus t-f-r blocks incurred faster response times with performance accuracy maintained, then the attentional underpinnings responsible would be revealed.

The previous experiment was not able to clarify whether there were differences in perceptual load as a result of local feature similarities between angry template-matching inputs and the sad, disgusted, surprised, or happy valence inputs. Therefore, experiment three included valence of the other emotion as an experiment factor.

4.3.1: *Behavioural findings*

Previous research findings have demonstrated rapid sub-cortical activation to and attentional prioritisation for threat (e.g., Eimer & Holmes, 2009; Fox et al., 2001; Pourtois et al., 2013). The findings from experiment one showed that faster and more accurate behavioural performance was associated with angry t-f-s, versus t-f-r blocks, suggesting it was easier to attend to, than ignore angry valence. It was therefore, hypothesised that faster and more accurate responses would be associated with the angry t-f-s, versus t-f-r blocks in experiment three. The behavioural data for the current experiment confirmed that faster and more accurate responses were associated with angry t-f-s, versus t-f-r blocks; this demonstrates the resistance of threatening (angry) valence to active suppression and the capacity for angry valence to draw and hold attentional focus. On happy valence trials the direction of the t-f-s, versus t-f-r difference was reduced. It is possible that a positive stimulus bias accelerated selection of happy valence so that it was responded to faster when it was a target, in comparison to when disgusted, sad and surprised valence appeared as targets. Indeed, previous findings (Holmes et al., 2009) showed that when a neutral face was paired with a happy, or angry face, there was no significant difference between response times to probes that replaced happy, versus angry facial expressions.

It is also plausible that there was better local feature discrimination between angry and happy expressions (mouth downturned, versus upturned, respectively) in comparison to the other (sad, disgust, surprised) emotions (see appendix D for face stimuli used) in experiment three. This could have reduced task difficulty when angry template displays contained happy valence. Increased cognitive demands have been shown to heighten the capacity for threatening valence to capture and hold attention (Holmes et al., 2014); thus, if cognitive demands were lower due to easier local feature discrimination on happy valence trials, then this may have reduced the capacity for angry valence to hold attentional focus which could explain the reduced difference between response speed for angry t-f-s, versus t-f-r when happy valence appeared on the display. If cognitive demands were reduced due to increased local feature dissimilarities when displays contained happy valence, versus sad, disgusted and surprised valence, then the ERP indexed Ppc component may show increased laterality divergence when the angry template appeared with happy valence in comparison to when angry valence appeared with the other emotions. This is because the Ppc has been demonstrated to index early identification of local feature differences

(see Fontier-Gauthier et al., 2012; Leblanc et al., 2008; Luck & Hillyard, 1994). Indeed, Ppc laterality divergence was greater in the previous experiment two when the neutral template face appeared with happy, as compared against the other emotional faces; though notably, experiments two and three used different template valence so local feature dissimilarities may have been greater for neutral, than angry templates with respect to happy valence faces.

The current behavioural data further revealed that overall, accuracy was most impaired when displays contained disgust valence, with incremental improvements according to displays with sad, happy, then surprised valence. A likely explanation for the finding may be that there were more feature similarities (e.g., relating to eye and mouth set) between angry, disgusted and sad faces, than between angry, happy and surprised facial valence. For example, angry, versus surprised facial expressions depicted eyes squinting, versus eyes wider open, respectively. Thus, local feature discontinuities may have been used to improve valence discrimination on some trials more than others. It was suggested above that greater local feature discontinuities may have reduced cognitive demands leading to decreased capacity for the angry template to capture and hold attentional focus on happy valence trials. Assuming that high accuracy for displays containing surprised valence was also driven by ease of local feature discriminability, then cognitive demands would presumably have been low not only when angry templates appeared with happy valence, but also when presented with surprised valence. It therefore, seems that the first explanation, a positive stimulus bias for happy valence, likely underpinned the diminished response time difference between angry t-f-s, versus t-f-r when happy valence appeared on the display.

4.3.2: *ERP findings*

4.3.2.1: *Ppc:* 70-128 ms

Experiment two revealed enhanced Ppc laterality divergence when displays contained happy facial valence, versus disgust and sad facial valence which likely reflected greater local feature discontinuities between neutral and happy face stimuli, when compared against neutral and disgust/sad face stimuli. Support was given for previous research findings that suggest the Ppc index's early identification of salient feature discontinuities on visual displays (see Fontier-Gauthier et al., 2012; Leblanc et al., 2008; Luck & Hillyard, 1994). It was suggested in the introduction to the

current experiment three that there may have been greater perceptual similarity between angry and sad/disgust inputs than between angry and happy/surprised inputs. It was therefore, hypothesised that PPC laterality divergence would be enhanced when angry template displays contained happy and surprised valence, as compared against sad and disgust valence.

The hypothesised pattern of PPC laterality divergence was not supported by the current experiment three data as PPC laterality divergence was not modulated by valence of the other emotional face, or by the other experiment factors. It is likely that in comparison to the neutral template faces in experiment two, angry template faces in experiment three had reduced local feature differences with respect to the happy valence faces. The finding provides useful context to interpretation of any subsequent valence-driven attention effects as valence-driven modulation to early and late attention may be more confidently attributed to the effects of emotion on attention processing rather than to local feature differences.

4.3.2.2: *Early attention interval:* 148-188 ms

Threatening valence has been shown to capture attention (for reviews see Compton, 2003; Vuilleumier & Hung, 2009). Previous investigation into the neurophysiological profile associated with post-capture dynamics (Liesefeld et al., 2017) revealed that a laterally presented distractor which was more salient than a midline presented target initially captured attention as an ND opposite the salient distractor emerged during the early attention interval. Following this, Liesefeld et al. (2017) found that during late attention processing salience-driven attentional capture was actively suppressed, indexed by the presence of a PD opposite the salient distractor. Experiment two of this thesis revealed that the laterally presented face captured attention irrespective of task (t-f-s vs. t-f-r) or emotional valence of the other face, suggesting that faces may have an innate capacity to capture attention. The finding was unexpected as due to the exogenous nature of early attentional capture it had been expected that lateral emotion would capture attention more than the neutral template.

Given the high socio-motivational status of angry template valence, for experiment three it was hypothesised that during the early attention interval there would be enhanced attentional capture (enhanced contralateral negativity) for angry template inputs, versus other emotion inputs irrespective

of task-goals. The findings for the current early attention interval did not support the hypothesised effects, but instead reflected the profile of response that emerged for experiment two. Early attentional capture was equivalent irrespective of task-goals or valence of the non-template face, suggesting that all faces initially captured attention.

With respect to the most recent revision of the signal suppression hypothesis, Gaspelin and Luck (2019) stipulated that distractors can be reactively, or proactively suppressed. They noted that reactive suppression, meaning that distractors are selected prior to being suppressed, has tended to occur when sufficient experience has not been gained with a learned distractor feature. Conversely, proactive suppression, meaning that distractors are suppressed without prior selection, has been evidenced to emerge when there is sufficient selection history experience with a learned distractor feature. Gaspelin and Luck (2019) posited that repeated exposure to a specific distractor feature (selection history learning) can reduce the gain for respective feature values before stimulus onset, allowing matching inputs to be more easily suppressed. Gaspelin and Luck's (2019) reactive, versus proactive suppression account was based on evidence garnered from colour singleton and inanimate feature processing (e.g., Bundeson et al., 2005; Chelazzi et al., 1998; Cunningham & Egeth, 2016; Gaspelin & Luck, 2018; Moher & Egeth, 2012; Sawaki & Luck, 2010). The authors noted that as yet the neurocognitive profile of template guided suppression for real world objects is not known.

At the time of writing only one previous investigation (Bretherton et al., 2017) was known of that isolated neural mechanisms for suppression of stimuli with high socio-motivational significance. This work revealed that an ND component response was evoked by lateral angry facial valance prior to the emergence of a PD component which indicated that emotional facial valence automatically captured attention before the attentional capture response could be suppressed; this was irrespective of whether the emotional face had target or distractor status. Moreover, as an ND (distractor elicited capture), versus PD (distractor suppression) response was evoked by respective intact, versus scrambled faces, this supported that that faces, unlike singleton stimuli, may not be directly suppressed because of their intrinsic social and biological importance. The current experiment three results strongly support this interpretation. In contrast to the Bretherton et al. (2017) paradigm, current participants had conceptual as well as selection

history learned template representations (participant were told what the template valence was and the template valence appeared on every trial); however, this did not trigger the use of socio-emotional stimuli for proactive suppression during early attention processing. Taken together the converging evidence suggests that proactive suppression of facial valence inputs may not be possible because such stimuli communicate consequential social information such as threat or benefit that could prove socially or biologically detrimental to proactively ignore.

4.3.2.3: *Late attention Interval:* 224-264 ms

The previous (experiment two) of the thesis hypothesised that there would be evidence of controlled attention processing during the late attention interval. In fact the data from that experiment did not support the hypothesised effects. There was some modulation of the selection response according to task, but only for lateral emotion, not for lateral templates. It was not till the late SPCN interval that strong evidence for controlled processing emerged. The interpretation for the late attention findings in experiment two was that the high socio-motivational salience of faces likely reduced controlled processing during the attention intervals. Given the experiment two late attention findings and given that for the current experiment angry template valence (which had higher socio-motivational salience than neutral template valence) was the t-f-s or t-f-r, it was expected that for experiment three there would be increased stimulus-driven processing, compared to experiment two during the late attention interval. It was hypothesised that this would emerge as enhanced attentional selection (contralateral negativity) for angry template-matching inputs, versus other emotion inputs, irrespective of task-goals. The current late attention findings did not support the hypothesis as significant laterality divergence emerged to none of the laterally presented faces. Notably, the profile of the ERP wave-form visually depicted laterality divergence during the late attention interval. It was noted in the methods section that greater than expected participant attrition resulted in a smaller sample than intended. It is therefore, possible that with a larger sample significant laterality divergence may have been revealed for the late attention interval.

4.3.2.4: *Late sustained processing interval:* 280-500 ms

The previous experiment two findings demonstrated that controlled goal-driven processing did not emerge till late sustained processing (termed SPCN). The evidence supported that uploading and maintenance of visual stimulus representations in VWM was prevented (sustained contralateral positivity SPD), or enhanced (sustained contralateral negativity- SNT) according to whether the lateral stimulus was respectively a distractor (lateral t-f-r and midline t-f-s) or target (lateral t-f-s and midline t-f-r). The finding was interpreted as evidence that uploading and maintenance of stimulus representations in VWM could be strategically controlled according to task goals in order to a) maintain above chance level accuracy and b) facilitate consistency of task performance between the experiment conditions. It was suggested that if the template valence had been of more similar socio-motivational salience to the other emotions (sad, disgusted, surprised, happy), then enhanced goal-driven processing for template-matching inputs may have been found.

The current experiment three used angry valence as the t-f-s or t-f-r. The same emotional faces (happy, sad, surprised, disgust) appeared as the other face on sparse displays. It was expected that there would be a sustained contralateral negativity (SNT) opposite angry t-f-s inputs, versus a sustained contralateral positivity (SPD) opposite angry t-f-r inputs. The direction of sustained processing effects were expected to be more pronounced in comparison to the sustained contralateral negativity (SNT) versus positivity (SND) opposite emotional target and distractors inputs on midline t-f-r and t-f-s trials respectively.

Contrary to the predicted direction of effects, the data revealed enhanced SPCN laterality divergence opposite angry template inputs, compared with the other emotion inputs, irrespective of task. A possible explanation for the unexpected SPCN findings is that angry valence may have been resistant to controlled suppression because of feedforward amygdala influences on ventral processing (see Pourtois, Schettino, & Vuilleumier, 2013; Vuilleumier, & Schwartz, 2001a, 2001b). Additionally, cognitive demands in experiment three were likely very high (see Holmes et al., 2014 who found threat captured and held attention more when cognitive resources were depleted)

because a) both faces had high socio-motivational salience and b) the faces in experiment three more perceptually difficult to dichotomise (see appendix D for faces used). If angry template inputs were resistant to controlled suppression and attentional control resources were limited in experiment three, then in the angry t-f-r block an alternative route to maintaining task accuracy above chance level may have been used. The data for the early attention interval showed that all face inputs initially captured attention. It is possible that early capture was sufficient for participants to identify the sex of the other emotion when it was a target (t-f-r block). Some cost to task performance would though, be expected in the experiment three t-f-r block, when compared to the experiment two t-f-r block for which goal-driven modulation of sustained processing was seen. Overall slower and less accurate task performance was revealed for the current (angry templates), versus the previous (neutral templates) experiment and most notably, while behavioural performance was maintained between the previous neutral t-f-s, versus t-f-r conditions, the same was not the case for the current experiment as slower and less accurate responses were recorded when angry valence was a t-f-r, versus a t-f-s. The current findings suggest that above chance level performance can be maintained in the absence of controlled processing, but not without a cost to task performance.

Chapter 5: Singleton templates-for-rejection on crowded versus sparse displays

5.1: Introduction

Interactions between bottom-up (automatic) and top-down (controlled) processing underpin selection of task-relevant stimuli (e.g., Bundesen, 1990; Desimone & Duncan, 1995; Neisser, 1967; Treisman, 1988; Wolfe, 1994). Some neural theories of visual attention (e.g., Bundesen, 1990; Bundesen et al., 2005; Desimone & Duncan, 1995) stipulate a role for top-down guidance in configuring mechanisms of perceptual attention to preferentially select objects with target matching features.

Desimone and Duncan's (1995) Bias Competition Theory (BCT) postulates that stimuli compete for attentional representation by means of mutual neural suppression (see Beck & Kastner, 2009; Chalazzi et al., 1998; Kastner et al., 2007; Kastner et al., 1998; Schluppeck et al., 2006 for supportive evidence) that works to filter out competing inputs in order to narrow the attentional spotlight. When a stimulus wins the competition for processing resources, this normally occurs because it accumulates greater activation of neural networks that dynamically respond to the stimulus with the highest visual or motivational salience.

The Neural Theory of Visual Attention (NTVA) (Bundesen, 1990; Bundesen et al., 2005) proposes that target representations maintained in visual working memory (VWM) during visual search interact with attention networks in the inferotemporal cortex to set high attentional weights for inputs that match target features.

In addition to theories regarding neural processing that underpins target selection, recent hypothesis testing has surrounded neural processing behind distractor suppression. One such study was carried out by Woodman and Luck (2007) who observed faster target identification when search distractors matched, versus did not match, a colour feature being held in working memory that was known to never match the target. They proposed that the working memory representation was used as a template-for-rejection to bias attention away from task-irrelevant inputs during multiple item search

such that features known to be task-irrelevant may be used to avoid the processing of feature-matching nontargets in our field of view.

The idea that visual attention can be biased away from nontarget items appears to be compatible with NTVA as, if visual working memory (VWM) representations can be used to dynamically set high attentional weights for feature matching inputs, then it may logically follow that VWM representations of known salient distractor features may be used to lower attentional weights for inputs that match those features. Indeed, the findings of a study carried out by Arita et al. (2012) were interpreted in support of the outlined extension to NTVA.

Arita et al. (2012) presented four, eight, or twelve squares clockwise around a central fixation cross. Half the squares appeared on the left in a different colour to the squares on the right of the central fixation cross. One square (the target) contained a unique gap position when compared with the distractor squares. Negative (distractor cue), positive (target cue) and neutral (irrelevant cue) blocks indicated the relevance of the colour that was cued at the beginning of each trial. Targets were identified more quickly on negative, compared to neutral cue blocks for eight and twelve item search. On four item search there was no significant difference between target identification speed for negative and neutral blocks. Arita et al's. (2012) interpretation of the findings was that attentional weights were lowered for stimuli with the t-f-r feature as a means to actively avoid processing irrelevant items. This may indeed have occurred; however, the findings could also have emerged if a strategy of converting the feature cue into a spatial cue had been used. As the target appeared in one of two colours which appeared on separate halves of the array, it is possible that the side of the array containing the distractor colour could have been rapidly selected before attention was re-allocated to the opposite side of the array that would contain the target. If the alternative strategy was used then rather than feature matching inputs being deprioritised for processing, Arita et al. (2012) may instead have demonstrated that distractors which matched the VWM maintained feature were initially selected prior to attentional reallocation. Such a strategy would likely result in a t-f-r benefit when a high (eight and twelve item search), but not a low (four item search) number of items was searched.

In contrast to the likely process by which distractors were suppressed in the Arita et al. (2012) study, research carried out by Sawaki and Luck (2010) uncovered ERP evidence that a salient, but task irrelevant distractor was actively suppressed prior to capturing attention. The authors subsequently proposed the Signal Suppression Hypothesis of attentional capture (SSH), which states that salient items elicit an 'attend to me' priority signal that can be actively suppressed prior to capturing attention.

Further studies have put forward contrasting accounts with respect to the neural underpinnings of distractor suppression (e.g., Beck et al., 2018; Cunningham & Egeth, 2016; Gaspelin & Luck, 2018; Moher & Egeth, 2012; Sawaki & Luck, 2010); for instance, an experiment carried out by Cunningham and Egeth (2016) varied pre-cue versus no pre-cue trials and also switched the cued colour between trials. No performance-related benefit to pre-cueing distractor colour was revealed as accuracy and response speed were unaffected by cue type. Notably, the salient distractor in Sawaki and Luck's (2010) experiment only ever appeared in one colour, while the other array items appeared in another colour. Taken together, these findings demonstrate that learning to ignore a specific distractor feature through selection history, rather than simply through top-down task set, may be necessary for mechanisms of proactive suppression to work. This was suggested in a recent review; Gaspelin and Luck (2019) proposed as an extension to the SSH that when a template signal can be reliably predicted, neural network gain control for feature-matching inputs can be prevented, whereas when a template signal cannot be reliably predicted, feature-matching inputs must be selected before they can be suppressed. Thus, Gaspelin and Luck's (2019) *proactive suppression* and *reactive suppression* accounts respectively refer to which factors determine whether a) attentional selection will occur prior to suppression of non-targets, or b) non-target suppression will occur without prior non-target selection.

While Gaspelin and Luck's (2019) proactive and reactive suppression accounts do explain contradictory findings between previous investigations, the authors themselves stated that their extension to the SSH was exclusively based on the data from singleton search paradigms, and they called for research into the neurocognitive profile associated with template-guided-suppression for real-world items.

Experiments one, two and three of the current thesis revealed that template-guided-suppression for stimuli with socio-motivational significance appeared to be accomplished by means other than reactive or proactive suppression which was likely because inputs with socio-motivational salience were more resistant to controlled processing than inanimate singleton items, especially when the socially relevant items depicted threat (experiment three). A plausible explanation for the findings is that avoidance of emotion in real world environments may not be a socially or evolutionarily viable response.

Of particular interest with respect to the previous experiments was the finding that when the template face was neutral (experiment two) ERP components that would normally reflect controlled attention processing, appeared to index a more stimulus-driven response; whereas the profile of the late sustained processing interval (termed the SPCN component Dell'Acqua et al., 2006; Jolicoeur et al., 2006; Klaver et al., 1999; Vogel & Machizawa, 2004), appeared to reflect that template-guided suppression and selection, was achieved through respective prevention, or enhancement of uploading and maintenance of visual stimulus representations in VWM.

With respect to WM processing Miyake, Friedman, Emerson, Witzki, and Howerter (2000) conducted a latent variable analysis and identified three executive functions. One of which, the updating function, was described by the authors as involved in the monitoring and updating of working memory (WM) representations in relation to their relevance to ongoing tasks (also see Eysenck et al., 2007; Lehto, 1996; Morris & Jones, 1990). Updating was described as one of three identified executive functions and was the only function identified as not heavily influenced by attentional control. In contrast, the other two executive functions identified by Miyake et al. (2000) were described as subject to attentional control; these were "mental set shifting (''Shifting''), and inhibition of prepotent responses (''Inhibition'') (Miyake et al., 2000, p. 49). Inhibition was described by the authors as the "ability to deliberately inhibit dominant, automatic, or prepotent responses when necessary" (Miyake et al., 2000, p. 57). Thus, inhibition refers to one's ability to control attention and avoid distraction by irrelevant items. The term shifting was used by Miyake et al. (2000) to describe shifting back and forth between multiple tasks, mental sets, or operations. Terms analogous to shifting have been previously used to

explain cognitive failures as a result of switching between multiple operations during a given task (see Monsell, 1996; Lavie et al., 2004; Lavie, 2010).

The previous experiments of the current thesis, did not require use of the shifting function as neutral (experiment one and two), or angry (experiment one and three) facial valence was sustained as either a t-f-r, or t-f-s throughout a given experiment block. However, as previously discussed, reduced attentional control was observed during these experiments, likely due to the high emotional salience of the search stimuli employed leading to a more bottom-up processing response, and in experiment three possibly also due to increased task demands as a result of using face stimuli that were perceptually difficult to discriminate from one another. In contrast to the previous experiments, the current experiment four will employ colour singleton stimuli, but will aim to increase load on cognitive resources by necessitating use of the shifting function. To do this, the colour of the search distractor will be preceded by a relevant cue (plus sign will indicate that the distractor will match the cued colour) on twenty consecutive trials, followed by an irrelevant cue (minus sign will indicate that the distractor will not match the cued colour) for twenty consecutive trials. Cue order will be counterbalanced across participants. Monitoring for cue change will result in high task demands during experiment four. Further to monitoring for the cue change, participants will also be required to switch the feature maintained in VWM as cue colour will also change between trials. It is expected that the paradigm will result in reactive, rather than proactive suppression of t-f-r inputs. To examine effects of task difficulty on the neurocognitive profile associated with reactive t-f-r suppression, distance between stimuli that appear on the current search displays will be manipulated. Previous research showed that increasing the relative distance between target and distractor items decreased inter-stimulus competition leading to faster and more accurate target detection for target and distractor items that were further apart, relative to closer together (see Hickey & Theeuwes, 2011; Gaspar & McDonald, 2014; Liesefeld et al., 2017). It is therefore expected that in experiment four, on easy trials (sparse displays- where the target and distractor appear further apart) more resources will be available for controlled processing; whereas on hard trials (crowded displays- where the target and distractor appear closer together) relatively fewer resources will be available for controlled processing. This should result in better post-capture

suppression (enhanced late attention PD laterality divergence opposite the cued t-f-r input) on sparse, versus crowded displays.

With respect to "inhibition of prepotent responses (''Inhibition'')" (Miyake et al., 2000, p. 49), it was considered in the discussion sections of experiments two and three, though particularly experiment three, that the high socio-motivational salience of the search items evoked a more stimulus-driven, than goal-driven attentional processing response. As previously mentioned, in experiment two (neutral templates), there was evidence that modulated uploading and maintenance of stimulus representations in VWM was strategically used to overcome reduced "inhibition" during the early and late attention intervals. In contrast, it was suggested that during experiment three, as compared with experiment two, task demands were high because of the increased socio-motivational salience of the stimuli presented during search (both items were emotional) and because of the increased difficultly with respect to identification of the angry valence templates from the perceptually similar emotional faces. These factors could have increased task difficulty and thus reduced controlled processing (see Lavie et al., 2004 Load Theory) which may have been responsible for the finding that the late sustained processing interval (SPCN interval) in experiment three (angry templates) did not appear to reflect strategic manipulation of uploading and maintenance of visual representations in VWM as had been seen for experiment two. Task difficulty will be high for the current experiment four, though colour singletons will be used, rather than stimuli with socio-motivational value. It is of interest to uncover whether as with experiment two task performance will be maintained at the level of VWM processing, or whether a profile more consistent with Gaspelin and Luck's (2019) reactive suppression account will emerge.

For experiment five it was expected that:

a) If reactive suppression occurs, this will emerge initially as attentional capture opposite both cued t-f-r inputs and non-cued distractor inputs during the early attention interval. During the late attention interval the early capture response will subsequently be suppressed and

suppression will be enhanced (increased PD laterality divergence) opposite cued t-f-r inputs, versus non-cued distractor inputs.

b) If reactive suppression does not occur because of high task demands in experiment four, then task performance is expected to be maintained in VWM by prevention (SPD-sustained contralateral positivity), versus enhancement (SNT- sustained contralateral negativity) of uploading and maintenance of the visual representation of respective distractor, versus target inputs. It is possible that the SPD response may be enhanced for cued t-f-r representations.

A further ERP component, namely the PPC, has been shown to index pre-attentive identification of salient featural discontinuities to facilitate subsequent controlled attentional deployment (Fontier-Gauthier et al., 2012; Leblanc et al., 2008).

c) Evidence for early identification of the cue matching t-f-r would emerge as increased PPC laterality divergence on cued t-f-r trials versus non-cued trials.

d) Evidence that PPC indexed early identification of t-f-r presence prepares controlled attention deployment would emerge as reactive suppression of cued t-f-r inputs (PD opposite t-f-r input), versus non-cued distractor inputs (ND or reduced PD opposite non-cued distractors); whereas If PPC laterality diverges more on cued t-f-r trials than on non-cued trials, but this does not lead to more controlled reactive suppression for cued t-f-r inputs, versus non-cued distractors, this would suggest that PPC indexed early identification of t-f-r inputs may at least not always facilitate subsequent controlled attentional deployment.

The current experiment four will employ a Hickey et al. (2009) style array. Prior to array onset, a pre-cue screen will be presented. In groups of twenty consecutive trials, the pre-cue will indicate

(with a plus or minus sign) either the colour of the proceeding search distractor (relevant pre-cue), or a colour that will match neither the search distractor nor the search target (irrelevant-cue). An 800ms post-cue delay will allow adequate time for the cued colour to be assimilated prior to target search (see Moher & Egeth, 2012). Following this, target search displays will present briefly with one stimulus directly above or below the central fixation cross, and the other stimulus at one of four possible left or right sided positions. This lateral stimulus will be positioned slightly above or below the horizontal midline so that it is close to (crowded display), or further from (sparse display) the vertically centralised stimulus. As previous studies (e.g., Hickey & Theeuwes, 2011; Gaspar & McDonald, 2014; Liesefeld et al., 2017) found faster target identification when a salient distractor appeared further from, versus closer to the search target, it was expected that:

e) Faster target identification for sparse, versus crowded array trials would be associated with improved attentional control which would emerge as enhanced post-capture suppression for cued t-f-r, versus non-cued distractor inputs on sparse, as compared against crowded array trials.

5.2: Methods

5.2.1: *Participants*

A statistical power analysis was performed in GPower 3.1.9.4 for sample size estimation. The effect size and partial eta squared values used for the experiment four power analysis were the same as those entered for the experiment two and three power analyses ($F = 3.25$, $\eta p^2 = .17$). Additionally, the more conservative alpha and power values ($p < .01$, power = .85) were considered appropriate because experiment four was a 2 x 2 x 2 x 2 x 5 repeated measures ANOVA. This constituted additional factors when compared the 2 x 2 x 2 x 3 repeated measures ANOVA reported by Holmes et al. (2009) from which the original (experiment one) power analysis values were derived. The projected sample size was N = 20.

Twenty-three University of Roehampton students gave informed consent prior to participation and received course credit recompense. One participant was removed due to low accepted trial numbers (> 25% rejected trials) after artefact rejection for horizontal and vertical eye movements. Three additional participants were removed because accuracy (Acc) in at least one condition fell below 70%. Of the remaining nineteen participants (fifteen female) one was left-handed. Age ranged eighteen to twenty-seven (mean ± SD age = 20.11 ± 2.16 years) and all reported normal or corrected-to-normal vision. Normal colour-vision was confirmed through administration of the Ishihara tests for colour blindness. The experiment was performed in compliance with The University of Roehampton ethical and research guidelines and was approved by the University ethics committee.

5.2.2: *Stimuli and Apparatus*

Participants were seated in a darkened cubicle. A headrest was used to maintain a distance of 60 cm from a 21-in. ViewSonic computer screen with 800 x 600 pixel display and a refresh rate of 75Hz, connected to a Dell precision Pentium IV computer. E-Prime Psychology Software 2.0 (Schneider et al., 2002) was used for stimulus presentation and response collection. A purpose built response box was used to collect Acc and response time (RT) feedback.

With respect to the cue-array, the stimuli were six (20 x 20 mm) coloured squares (blue: rgb (0,148,204), green: rgb (5,221,0), yellow: rgb (221,221,0), orange: rgb (221,88,0): red rgb (221,0,5), and violet: rgb (221,0,221)) that appeared against a dark grey background (rgb: 53,53,53). The squares each occupied one of six possible stimulus positions (counterbalance across trials) on the clockwise circumference of an octagon (radius 10mm) that appeared at the centre of the screen, prior to the onset of the squares. The centre of each coloured square appeared 55 mm from the adjacent outer-edge of the octagon's six active segments at clockwise visual angles: 50°, 90°, 130° and 230°, 270°, 310°, for left sided and right sided locations, respectively. The octagon appeared with eight visually differentiable segments, of which seven segments were coloured light grey: rgb (191,191,191), in contrast to the *cue segment* which was dark grey: rgb (63,63,63) and contained a grey (rgb: 195,195,195) positive (+) or negative (-) symbol. On each trial, the *cue segment* was overlaid on one of the six active segments, counterbalanced across trials. The active segments were defined by their positions as each was clearly aligned with one of the six coloured squares that appeared at lateral left and right locations. The two inactive segments of the octagon where those positioned along the centre (top and bottom) of the octagon's vertical midline. A plus symbol on the cue segment indicated that the colour of the corresponding square should be maintained in short term memory for use on the proceeding search task. A minus symbol on the cue segment indicated that the colour of the

corresponding square was irrelevant and would therefore, not indicate the colour of either the distractor, or the target on the proceeding search task.

The inter-stimulus interval (ISI) was defined by a grey (7mm x 7mm) central fixation cross (rgb: 195,195,195) against a dark grey background (rgb: 53,53,53) that remained on-screen from the start of the ISI, till offset of the proceeding search task. For the search task, two square outlines (squares were: 11 x 11 mm with outline thickness: 2 mm) appeared simultaneously at two out of a possible six stimulus locations. The centre of the square on the vertical midline appeared directly above or below the central fixation cross, whilst the centre of the lateral square appeared at one of four clockwise positions around the circumference of the fixation cross: 70°, 110°, 250°, 290°. The centres of the vertical and lateral stimuli were 25 mm from the central fixation cross, therefore the squares subtended 3.6° of visual angle. Crowded versus sparse search displays (randomly intermixed within the experiment) were characterised by the relative positions of the two search stimuli; specifically, the crowded array contained a vertical midline stimulus above fixation and lateral stimulus at 70° or 290°, or a vertical midline stimulus below fixation and lateral stimulus at 110° or 250°, whereas the sparse array contained a vertical midline stimulus above fixation and lateral stimulus at 110°, or 250°, or a vertical midline stimulus below fixation and lateral stimulus at 70° or 290°. Of the two square outlines, the distractor was characterised by a gap missing from its horizontal left, or right side and the target was characterised by a gap missing from its vertical top, or bottom side (gap size: 5 mm). Following offset of the search display, the dark grey background remained on-screen during the inter-trial interval (ITI), after which the octagon cue appeared again which marked consecutive trial onset.

5.2.3: *Procedure*

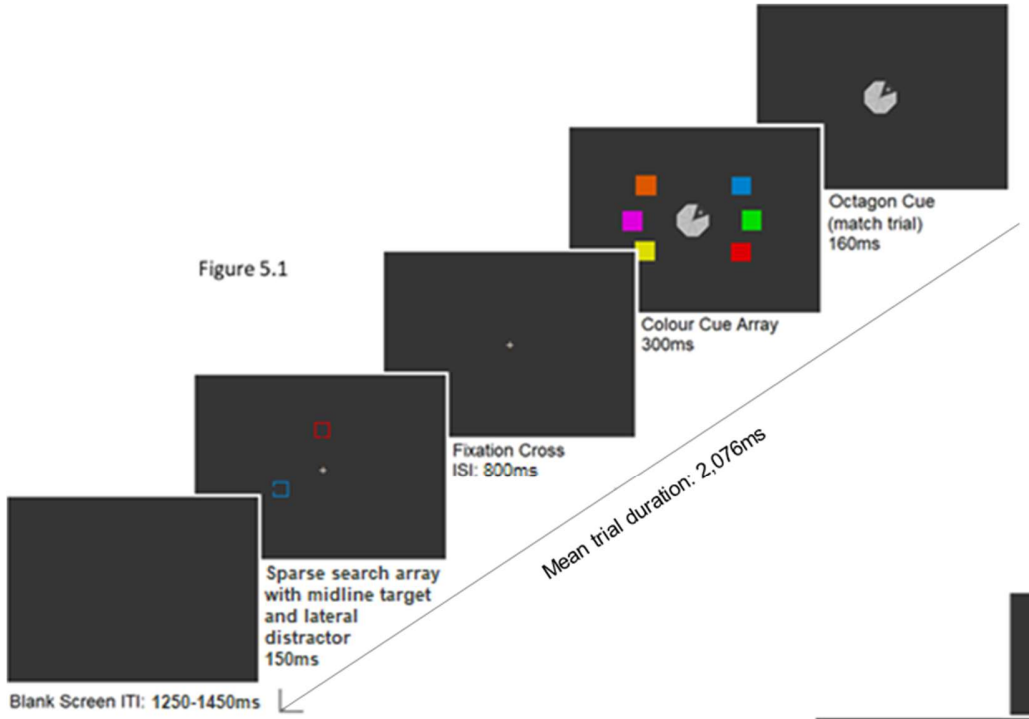
A total of 1,360 trials presented consecutive groups of 20 match trials, followed by 20 no match trials, or vice versa, counterbalanced across participants.

Each trial began with the onset of the octagon cue for 160ms prior to the onset of the coloured cue squares (cue array) that remained on-screen for 300ms. Prior to beginning experiment trials, participants were informed that the colour of the square adjacent to a positive cue (match trial) indicated the colour of the square on the proceeding search array that would not contain the target gap. It was made clear that the colour of the square adjacent to a negative cue (no-match trial) would not aid distractor elimination on the proceeding search array. Specifically, on match trials a template-for-rejection was provided, whereas on no-match trials no template-for-rejection was provided.

Offset of the cue array, was directly proceeded by onset of the central fixation cross for 800ms before the search stimuli appeared. The fixation cross and search stimuli (search array) remained on-screen for 150ms and responses were collected up till 1,400ms post array on-set. With respect to the search array, the target appeared on the vertical midline (top or bottom) with the distractor at a horizontal location (upper/lower left, or upper/lower right), or vice versa at equal probability.

In response to the search stimuli, participants were directed to report the position of the gap on the target- defined as the square outline with a gap missing from its top or bottom- using the first and second finger on their dominant hand and buttons one and two on the purpose built response box (button one for a top gap, button two for a bottom gap, or vice versa, counterbalance across participants). Following offset off the search stimuli, a blank screen appeared for ITI: 1250ms and

1450ms, after which the consecutive trial began. Every eighty trials (3.68 minutes) participants received an automatic break, wherein an onscreen message directed participants to press the space-bar when ready to continue experiment trials. Prior to beginning the experiment trials, participants received thirty-two practice trials with Acc and RT feedback, that could be repeated until >70% Acc was achieved.



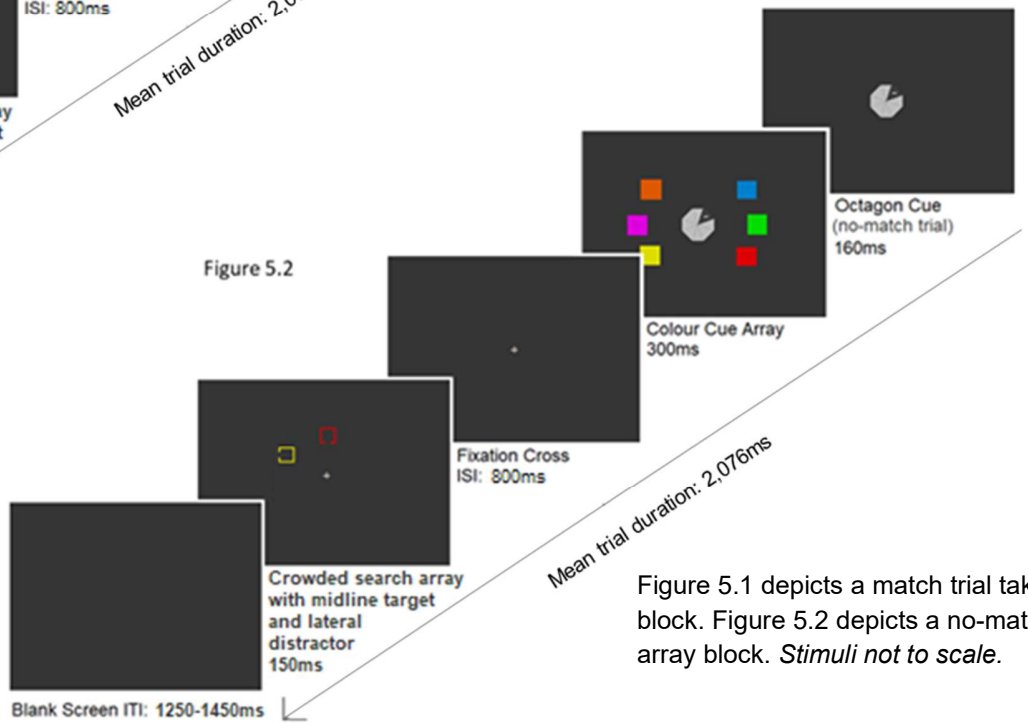


Figure 5.1 depicts a match trial taken from the sparse array block. Figure 5.2 depicts a no-match trial, taken from the crowded array block. *Stimuli not to scale.*

5.2.4: *EEG Data Acquisition*

EEG was recorded from 32 Ag-AgCl electrodes (Fp1, Fp2, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T8, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, O1, Oz, O2, PO7, PO8, PO9 and PO10 (according to the 10-20 system)), referenced on-line to the vertex and then re-referenced off-line to the average of the left/right mastoids. Horizontal EOG (HEOG) was recorded bipolarly from the outer canthi of both eyes and vertical EOG (VEOG) was recorded bipolarly, above the brow and below the left eye. See Figure 3 for electrode layout. All electrode impedances were kept below 5 kΩ; EEG and EOG were digitised with a 500 Hz sampling rate. The EEG was filtered online at d.c. to 100 Hz with vertex (CZ) as the online reference. Following EEG recording, data were digitally filtered offline with a bandpass of .3 Hz (24 db/oct) to 30 Hz (24 db/oct; zero-phase shift) using Neuroscan software (version 4.5). EEG and HEOG were then epoched into 600ms intervals, from 100ms before (pre-stimulus baseline) to 500ms after face pair onset. Trials with lateral or vertical eye movements (HEOG/ VEOG exceeding ± 40 μV and ± 80 μV, respectively) and trials with eyeblinks (Fp1/Fp2 exceeding ± 60 μV), or other artifacts (voltage at any electrode exceeding ± 100 μV) measured in each epoch were excluded from the analysis. Epochs were then re-referenced to the average of A1 and A2 ear lobe electrode locations.

Separate averages were computed for all combinations of distractor type (match, no-match) x array type (crowded, sparse) x distractor position (lateral, midline). Contralateral ERPs were the average of the left (P7) and right (P8) hemisphere electrodes for lateral stimuli presented to the right and left visual fields, respectively. Ipsilateral ERPs were the average of the left (P7) and right (P8) hemisphere electrodes for lateral stimuli presented to the left and right visual field, respectively; therefore, contralateral versus ipsilateral ERPs were the opposite, versus same-sided hemisphere to the lateral stimulus. Electrodes P7 and P8 were selected for analysis because contralaterality effects were maximal at those sites.

5.2.5: *Component time-window selection*

Visual inspection of the ERP waveforms, combined with previous research on contralateral components such as the Ppc, early N2pc interval, late N2pc interval and SPCN (e.g., Bretherton et al., 2017; Fontier-Gauthier et al., 2012; Grubert & Eimer, 2016; Hickey et al., 2009; Holmes et al., 2009; Holmes et al., 2013; Jannati et al., 2013; Woodman & Luck, 2003), resulted in identification of five ERP component time-windows that best represented the modulations of contralaterality effects (i.e., in attention processing) elicited by the current paradigm. Component time-windows were as follows: Ppc (80-120ms), early attention (134-168ms), late attention (246-280ms) and the SPCN (310-500).

5.3: Results

5.3.1: *Behavioural Results*

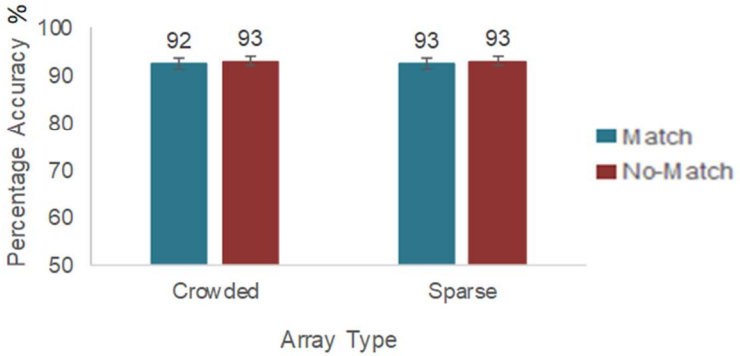
Non-responses and trials with response times (RTs) below 300ms were discarded; the subsequent mean and standard error of RTs for the sample was: M = 669.39 and SEM = 1.2, respectively. Mean percentage accurate responses (Acc) and mean RTs for each participant, were entered into a repeated measures analysis of variance (ANOVA) with the factors: distractor type (match vs. no-match), array type (crowded vs. sparse), and distractor position (lateral vs. midline). Note that for the match conditions, distractor colour was indicated prior to target search; whereas for the no-match conditions, the colour indicated prior to target search did not match the search distractor. Match, versus no-match trials were indicated by the presence of a + or – sign. There was no condition in which the target colour was pre-cued. Where post-hoc t-tests were carried out, the Bonferroni correction for adjusted alpha level (.05/number of tests) was applied. Where Mauchley's test for the assumption of sphericity was violated, Greenhouse-Geisser corrected values were reported with degrees of freedom taken from sphericity assumed.

Figure 5.4 (next page) depicts Acc (top panel) and RT (bottom panel) means for trials with lateral distractors (left graphs) and midline distractors (right graphs). Pairs of bars correspond to match (blue bars), versus no-match (red bars) trials, for array type: crowded (left pair), versus sparse (right pair). Error bars represent the standard errors according to distractor type, for lateral distractors separately to midline distractors.

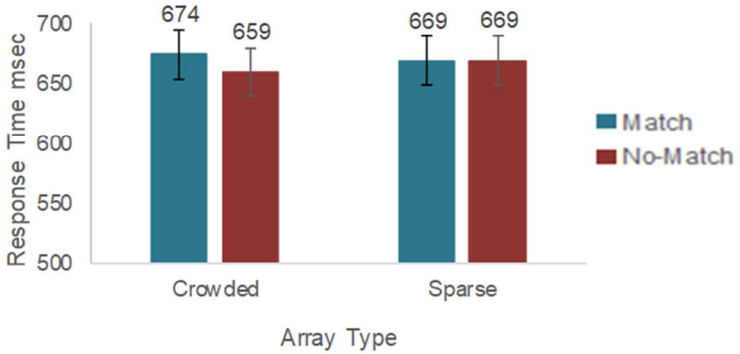
Lateral Distractor

Crowded Sparse

Lateral Distractor Accuracy



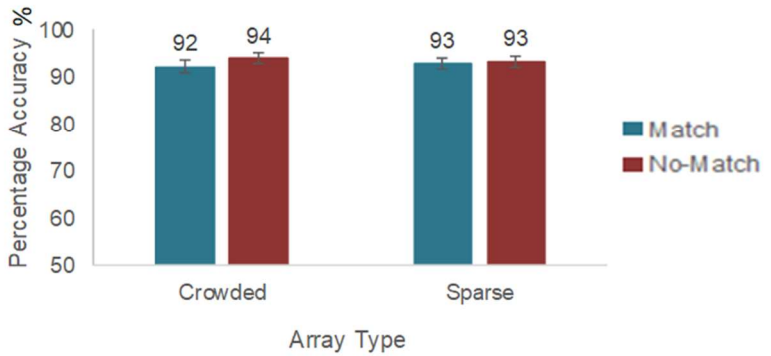
Lateral Distractor Response Time



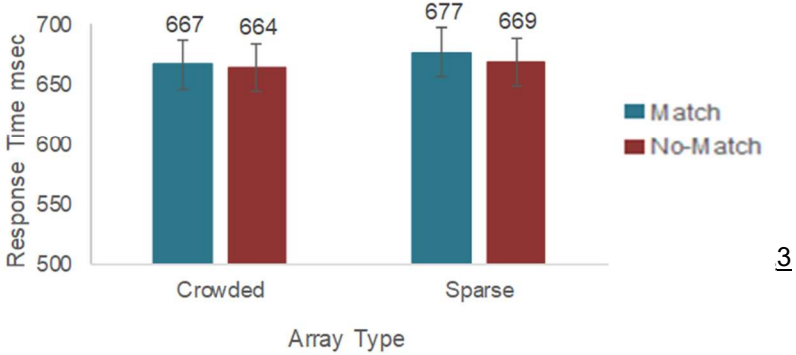
Midline Distractor

Crowded Sparse

Midline Distractor Accuracy



Midline Distractor Response Time



5.3.1.1: *Accuracy*

Distractor type significantly modulated Acc, $F(1,18) = 6.93$, $p = .017$, $\eta p^2 = .28$, as lower Acc was recorded on trials in which distractor colour was, versus was not pre-cued (respective means of: $M = 92.54\%$, $SEM = 1.11$ and $M = 93.26\%$, $SEM = .98$). Distractor position also differentiated Acc scores, $F(1,18) = 10.28$, $p = .005$, $\eta p^2 = .36$, as lower Acc corresponded to midline ($M = 92.13\%$, $SEM = 1.14$), versus lateral ($M = 93.67\%$, $SEM = .98$) distractor position. There was no main effect of array type ($F<1$).

There was a two-way array type x distractor position interaction, $F(1,18) = 5.11$, $p = .036$, $\eta p^2 = .22$. Follow-up t-tests with Bonferroni adjusted alpha .025 per test (.05/2) revealed that Acc was higher on crowded arrays containing lateral distractors as compared with midline distractors (respective means of: $M = 93.98\%$, $SEM = .94$ and $M = 91.8\%$, $SEM = 1.17$, $t(18) = 3.991$, $p = .001$). The same comparison was non-significant for sparse array trials (respective means of: $M = 93.36\%$, $SEM = 1.04$ and $M = 92.46\%$, $SEM = 1.17$, $t(18) = 1.578$, $p = .132$, *ns*).

There were no further interaction effects revealed for the ANOVA of accuracy scores (all $p \geq .05$).

5.3.1.2: *Response Times*

A main effect of distractor type ($F(1,18) = 8.64$, $p < .01$, $\eta p^2 = .32$), was in line with significantly slower responses on match (M = 671.61ms, SEM = 20.19), versus no-match trials (M = 665.52ms, SEM = 19.87). There was modulation of RTs according to distractor position ($F(1,18) = 63.52$, $p < .001$, $\eta p^2 = .78$), as faster RTs corresponded to trials with lateral distractors (M = 648.07ms, SEM = 20.27), versus midline distractors (M = 689.06ms, SEM = 20.07). No further main effects were uncovered (all $p \geq .05$).

A two-way distractor type x distractor position interaction ($F(1,18) = 8.59$, $p < .01$, $\eta p^2 = .32$) was followed up using post-hoc t-tests with Bonferroni adjusted alpha .025 per test (.05/2). There were significantly slower RTs recorded on match, versus no-match trials when the distractor stimulus appeared at lateral locations (respective means of: M = 653.92ms, SEM = 20.69 and M = 642.23ms, SEM = 19.91, $t(18) = 4.84$, $p < .001$). The same comparison did not approach significance when the distractor stimulus appeared at midline locations (respective means of: M = 689.31ms, SEM = 20.08 and M = 688.81ms, SEM = 20.18, $t(18) = .16$, $p = .88$, *ns*).

A significant two-way array type x distractor position interaction ($F(1,18) = 5.84$, $p = .027$, $\eta p^2 = .25$) was followed up. Post-hoc t-tests revealed a RT benefit for lateral distractor, as compared against midline distractor trials when participants searched crowded arrays (midline distractor: M = 689.23ms, SEM = 19.53, and lateral distractor: M = 643.03ms, SEM = 20.7, $t(18) = 7.495$, $p < .001$) and when participants searched sparse arrays (midline distractor: M = 688.89ms, SEM = 20.69, and lateral distractor: M = 653.12ms, SEM = 20, $t(18) = 7.272$, $p < .001$). This lateral distractor benefit was significantly greater for crowded arrays (midline minus lateral distractor RT

difference was *M* =46.2ms, *SEM* = 6.16) versus sparse arrays (midline minus lateral distractor RT difference was *M* =35.78ms, *SEM* = 4.92), $t(18) = 2.416$, $p = .027$.

No further interaction effects were revealed for the ANOVA of response times (all $p \geq .05$).

5.3.2: *Electrophysiological Results*

Incorrect responses, non-responses and RTs below 300ms, were not included in the ANOVA of mean ERP amplitudes. Figures 5.5 and 5.6 depict the ERP response profiles evoked by the lateral distractor on lateral distractor trials, and the lateral target on midline distractor trials, respectively. The left-most and central graphs of figures 5.5 and 5.6 show ERPs contralateral (dotted lines) and ipsilateral (solid lines) to the location of the lateral stimulus, observed at lateral parietal-occipital electrode sites P7 and P8. The right-most graphs of figures 5.5 and 5.6 show the contralateral minus ipsilateral difference waves. Displays in which the search distractor matched (match), versus did not match (no-match) the cued colour are depicted by the blue lines of figure 5.5 and green lines of figure 5.6, versus the yellow lines of figure 5.5 and red lines of figure 5.6, respectively. Indicated on each graph, are the component intervals selected for analysis: Ppc (80-120ms), early attention (134-168ms), late attention (246-280ms) and SPCN/P (310-500). Example stimulus displays appear at the top right of figures 5.5 and 5.6.

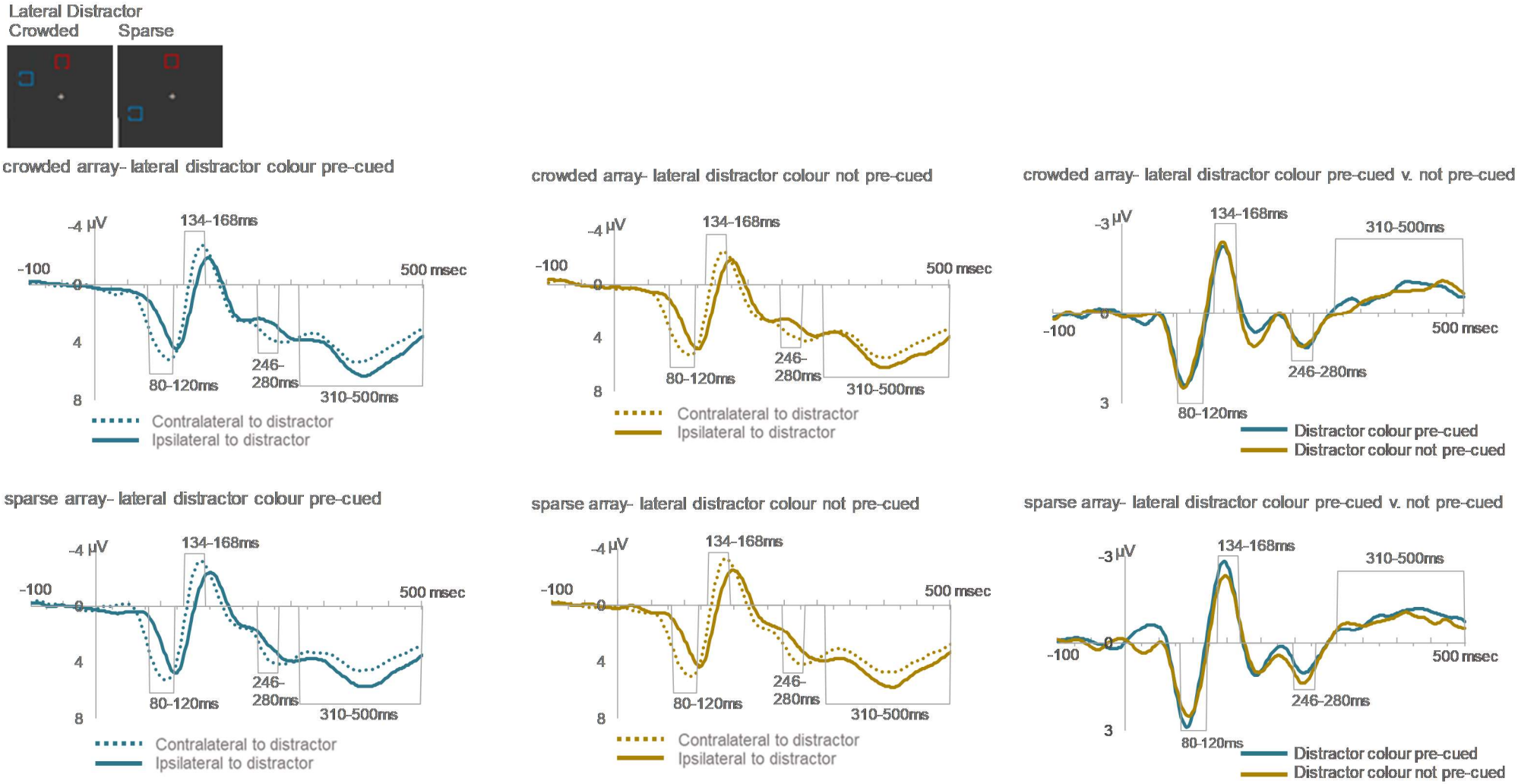

Lateral Distractor
Crowded
Sparse
crowded array- lateral distractor colour pre-cued
-4 µV
134-168ms
-100
500 msec
4
8
80-120ms
246-280ms
310-500ms
Contralateral to distractor
Ipsilateral to distractor
crowded array- lateral distractor colour not pre-cued
-4 µV
134-168ms
-100
500 msec
4
8
80-120ms
246-280ms
310-500ms
Contralateral to distractor
Ipsilateral to distractor
crowded array- lateral distractor colour pre-cued v. not pre-cued
-3 µV
134-168ms
310-500ms
-100
500 msec
3
80-120ms
246-280ms
Distractor colour pre-cued
Distractor colour not pre-cued
sparse array- lateral distractor colour pre-cued
-4 µV
134-168ms
-100
500 msec
4
8
80-120ms
246-280ms
310-500ms
Contralateral to distractor
Ipsilateral to distractor
sparse array- lateral distractor colour not pre-cued
-4 µV
134-168ms
-100
500 msec
4
8
80-120ms
246-280ms
310-500ms
Contralateral to distractor
Ipsilateral to distractor
sparse array- lateral distractor colour pre-cued v. not pre-cued
-3 µV
134-168ms
310-500ms
-100
500 msec
3
80-120ms
246-280ms
Distractor colour pre-cued
Distractor colour not pre-cued

Figure 5.5

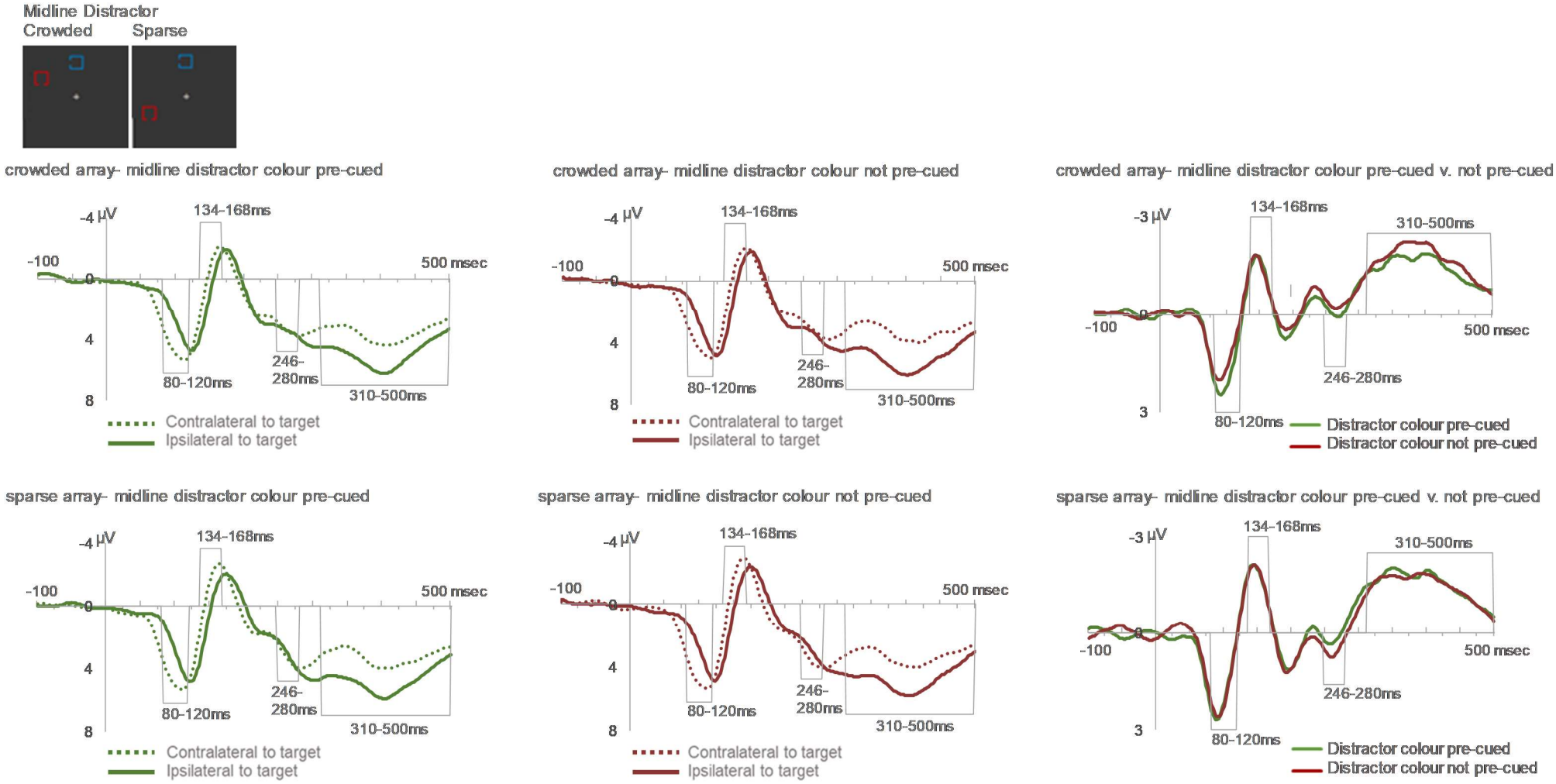

Midline Distractor
Crowded
Sparse
crowded array- midline distractor colour pre-cued
crowded array- midline distractor colour not pre-cued
crowded array- midline distractor colour pre-cued v. not pre-cued
sparse array- midline distractor colour pre-cued
sparse array- midline distractor colour not pre-cued
sparse array- midline distractor colour pre-cued v. not pre-cued
-4 µV
-3 µV
-100
0
4
8
3
500 msec
134-168ms
80-120ms
246-280ms
310-500ms
Contralateral to target
Ipsilateral to target
Distractor colour pre-cued
Distractor colour not pre-cued

Figure 5.6

5.3.2.1 *ANOVA: all conditions*

Mean ERP amplitudes were entered into a 4 x 2 x 2 x 2 x 2 repeated measures ANOVA, with the factors: component (intervals were: 80-120, 134-168, 246-280, 310-500 ms), laterality (contralateral vs. ipsilateral), distractor type (cued t-f-r vs. non-cued distractor), array type (crowded vs. sparse), and distractor position (lateral vs. midline). See experiment methods (*ERP Components*) for details regarding time-window selection. Where post-hoc t-tests were carried out, the Bonferroni correction for adjusted alpha level (.05/number of tests) was applied. Where Mauchley's test for the assumption of sphericity was violated, Greenhouse-Geisser corrected values were reported with degrees of freedom taken from sphericity assumed.

The main effect of component was confirmed, $F(3,54) = 12.37$, $p < .001$, $\eta p^2 = .41$), as mean ERP amplitudes recorded during the post-stimulus intervals: 80-120ms, 134-168ms, 246-280ms and 310-500ms, were: $M = 3.71$ μV, $SEM = .24$, $M = -.28$ μV, $SEM = .75$, $M = 3.23$ μV, $SEM = .92$ and $M = 4.27$ μV, $SEM = .71$, respectively. There was a highly significant main effect of array type, $F(1,18) = 20.88$, $p < .001$, $\eta p^2 = .54$), as mean amplitudes according to crowded, versus sparse arrays were: $M = 2.86$ μV, $SEM = .49$ and $M = 2.6$ μV, $SEM = .49$, respectively. The main effects of laterality, distractor type and distractor position were non-significant (all $p \geq .05$).

Although the main effect of laterality was non-significant, $F(1,18) = .85$, $p = .37$, $\eta p^2 = .05$, *ns*) there were highly significant two way interactions for component x laterality, $F(3,54) = 64.54$, $p < .001$, $\eta p^2 = .78$, and distractor position x laterality, $F(1,18) = 10.96$, $p = .004$, $\eta p^2 = .38$. Further two-way interactions were between component x array type, $F(3,54) = 8.61$, $p < .001$, $\eta p^2 = .32$, and component x distractor position, $F(3,54) = 13.03$, $p < .001$, $\eta p^2 = .42$. There were also three-

way interactions between component x distractor position x laterality, $F(3,54) = 24$, $p < .001$, $\eta p^2 = .57$, and component x array type x laterality, $F(3,54) = 7.75$, $p < .001$, $\eta p^2 = .3$. These two-way and three-way interactions were all encompassed within a significant four-way component x distractor position x array type x laterality interaction, $F(3,54) = 3.36$, $p = .025$, $\eta p^2 = .16$. The four-way interaction did not include the factor distractor type; however, because this factor was of central relevance to the research question, extrapolation of the interaction effects was carried out with distractor type (match vs. no-match) included.

The factors: laterality, distractor type, array type and distractor position were submitted to separate ANOVAs for each component (intervals were: 80-120, 134-168, 246-280 and 310-500 ms). Where there was a significant main effect of laterality, a subsequent ANOVA for that time-window was executed with the factors: distractor type, array type, and distractor position. The contralateral minus ipsilateral difference score then became the dependent variable representing the lateral stimulus elicited relative difference. Where the term *contralateral negativity* is used, this refers to relatively more negative amplitudes at contralateral, versus ipsilateral electrode locations (a negative relative difference). Where the term contralateral positivity is used, this refers to relatively more positive amplitudes at contralateral, versus ipsilateral electrode locations (a positive relative difference). The dependent variable change allowed laterality to be removed as a factor, thereby simplifying subsequent analyses.

5.3.2.1.1: *Ppc:* 80-120 ms

The main effect of laterality was highly significant ($F(1,18) = 32.67$, $p < .001$, $\eta p^2 = .65$) as mean amplitudes at contralateral, versus ipsilateral electrode locations were $M = 4.59$ μV, $SEM = .33$ and $M = 2.82$ μV, $SEM = .24$, respectively; therefore, the contralateral minus ipsilateral difference scores were entered into a three-way AVOVA with the factors: distractor type, array type and distractor position.

There was no main effect of distractor type, array type, or distractor position (all $p \geq .05$) and no interaction effects reach significance (all $p \geq .05$).

5.3.2.1.2: *Early attention interval:* 134-168 ms

The main effect of laterality was highly significant ($F(1,18) = 61.13$, $p < .001$, $\eta p^2 = .77$) as mean amplitudes at contralateral, versus ipsilateral electrode locations were $M = -1.14$ μV, $SEM = .81$ and $M = .57$ μV, $SEM = .71$, respectively. The contralateral minus ipsilateral difference scores were therefore entered into a three-way AVOVA with the factors: distractor type, array type and distractor position.

There was a main effect of distractor position ($F(1,18) = 25.81$, $p < .001$, $\eta p^2 = .59$), as the lateral stimulus was associated with an enhanced contralateral negativity on lateral distractor, compared with midline distractor trials (respective means of: $M = -1.9$ μV, $SEM = .21$ and $M = -1.51$ μV, $SEM = .23$). A significant main effect of array type ($F(1,18) = 5.79$, $p < .027$, $\eta p^2 = .24$) revealed that the contralateral negativity response to the lateral stimulus was greater on sparse, versus

crowded display trials (respective means of: M = -1.85 μV, SEM = .22 and M = -1.56 μV, SEM = .23). There was no main effect of distractor type (F(1,18) = .38, p = .545, ηp^2 = .02, *ns*) and no interaction effects reached significance (all $p \geq .05$).

5.3.2.1.3: *Late attention interval:* 246-280 ms

The main effect of laterality was confirmed (F(1,18) = 6.73, p = .018, ηp^2 = .27); mean amplitudes contralateral and ipsilateral to the lateral stimulus were M = 3.5 μV, SEM = .95 and M = 2.97 μV, SEM = .89, respectively. The contralateral minus ipsilateral difference scores were therefore, entered into a three-way AVOVA with the factors: distractor type, array type and distractor position.

A main effect of distractor position (F(1,18) = 46.53, p < .001, ηp^2 = .72) revealed an enhanced contralateral positivity response to lateral distractors (M = .98 μV, SEM = .23), versus lateral targets (on midline distractor trials), (M = .08 μV, SEM = .2). Further to this, there was a significant main effect of array type (F(1,18) = 5.36, p = .033, ηp^2 = .23), as an enhanced contralateral positivity was observed on sparse (M = .68 μV, SEM = .22), versus crowded (M = .38 μV, SEM = .21) array trials.

A two-way distractor position x array type interaction (F(1,18) = 7.6, p = .013, ηp^2 = .3) was followed up with Bonferroni adjusted alpha .025 per test (.05/2). On crowded array trials a contralateral positivity, versus negativity was evoked to the lateral distractor, versus the lateral target (on midline distractor trials); the respective means were: M = .95 μV, SEM = .23 and M = -.19 μV, SEM = .2, t(18) = 9.9, p < .001). On sparse array trials, a significantly enhanced contralateral positivity was in response to the lateral distractor, versus the lateral target (on midline distractor

trials); the respective means were: *M* = 1.02 μV, *SEM* = .26 and *M* = .35 μV, *SEM* = .23, *t*(18) = 3.47, *p* = .003).

No further interaction effects were observed during the 246-280 ms interval (all *p*≥.05).

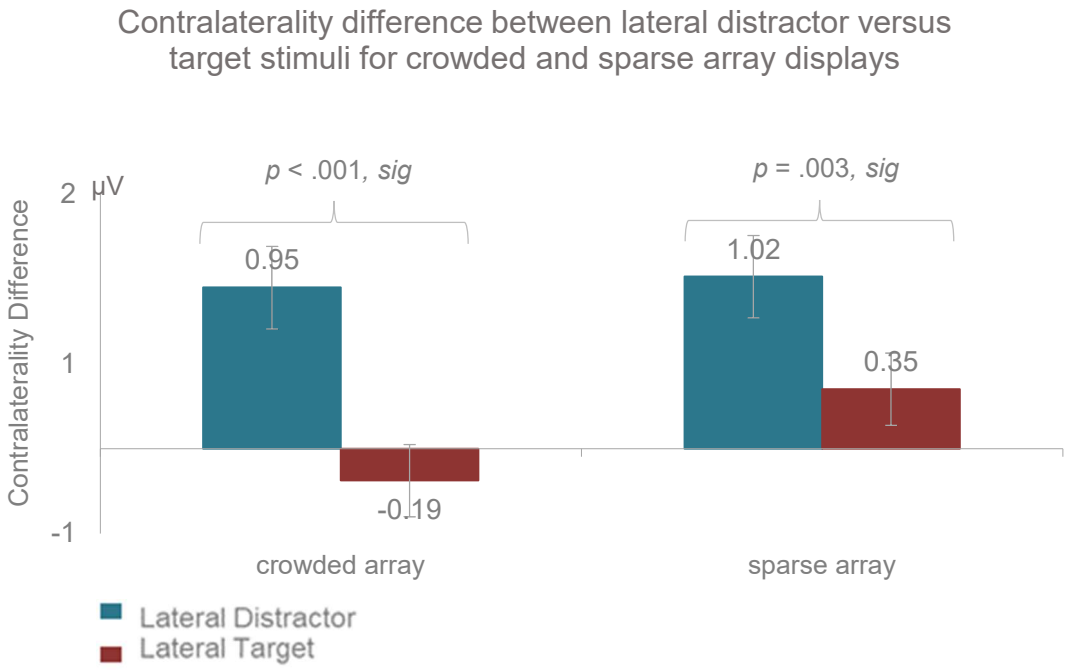


Figure 5.7 depicts the contralaterality difference to lateral distractors (blue bars), versus targets (red bars) on crowded (left bar pair) and sparse (right bar pair) arrays. Error bars represent the standard error for lateral distractors and lateral targets, averaged for crowded and sparse array displays. Significance level is indicated above the brace.

5.3.2.1.4: *Late sustained processing SPCN interval:* 310-500 ms

The main effect of laterality was highly significant ($F(1,18) = 131.71$, $p < .001$, $\eta p^2 = .88$); mean amplitudes contralateral, versus ipsilateral to the lateral stimulus were $M = 3.71$ μV, $SEM = .7$ and $M = 4.83$ μV, $SEM = .71$, respectively. The contralateral minus ipsilateral difference scores were therefore, entered into a three-way AVOVA with the factors: distractor type, array type and distractor position.

A main effect of distractor position emerged ($F(1,18) = 10.77$, $p = .004$, $\eta p^2 = .37$) as an enhanced contralateral negativity was observed in response to lateral targets (midline distractor trials), relative to lateral distractors (lateral distractor trials); the respective means were: $M = -1.5$ μV, $SEM = .19$ and $M = -.73$ μV, $SEM = .11$). There was no main effect of array type, or distractor type (both $F \leq 1$) and no interaction effects reached significance (all $p \geq .05$).

5.3.3: *Results Summaries*

5.3.3.1: *Accuracy and Response Times*

Slower and less accurate responses were associated with pre-cued t-f-r inputs, versus non-cues distractor inputs. Also revealed, was improved Acc and RTs when lateral t-f-r and distractor inputs were close to (crowded array), versus far from (sparse array) the simultaneously presented target.

5.3.3.2: *Electrophysiological Results Summary*

5.3.3.2.1: *Ppc:* 80-120 ms

There was significant laterality divergence in response to the lateral stimulus. This was not modulated by distractor type (match/no-match), distractor position, or array type. The finding supports the role of the Ppc component as an index of the identification of salient feature discontinuities.

5.3.3.2.2: *Early attention interval:* 134-168 ms

There was an enhanced contralateral negativity to (selection of) lateral distractors, versus lateral targets. An enhanced contralateral negativity was evoked by the lateral stimulus on sparse, versus crowded array trials.

5.3.3.2.3: *Late attention interval:* 246-280 ms

On crowded arrays there was a contralateral positivity to (suppression of) lateral distractors, versus a contralateral negativity to (selection of) lateral targets.

On sparse arrays there was a contralateral positivity to (suppression of) lateral distractors, that was significantly reduced to (less suppression of) lateral targets.

5.3.3.2.4: *late sustained processing SPCN interval:* 310-500 ms

There was an enhanced contralateral negativity to (sustained selection of) lateral targets, compared with lateral distractors.

5.4: Discussion

The current experiment employed an array analogous to that originally used by Hickey et al. (2009). Prior to array onset, a pre-cue screen appeared. In consecutive groups of twenty trials, the pre-cue indicated (with a plus or minus sign) either the colour of the t-f-r distractor (relevant pre-cue), or a colour that would match neither the search distractor nor the search target (irrelevant-cue). An 800ms post-cue delay followed offset of the cue array to allow adequate time for the cued colour to be assimilated prior to target search (see Moher & Egeth, 2012). Following this, target search displays presented briefly. One stimulus appeared directly above or below the central fixation cross, and the other stimulus at one of four possible left or right sided positions. This lateral stimulus appeared slightly above or below the horizontal midline so that it was close to (crowded display), or further from (sparse display) the vertically centralised stimulus.

The ERP findings in response to experiments two and three of the current thesis appeared to suggest that while attentional control was not adequate to proactively, or reactively (terms described by Gaspelin & Luck, 2019) suppress non-targets, the attention-related ERP components did indicate representation enhancement prior to the late sustained processing response. Attentional enhancement was more pronounced during experiment two (neutral templates), than three (angry templates). Resources for cognitive processing were considered to have been heavily taxed during the previous experiments because of the high socio-emotional salience of the stimuli displayed and with respect to experiment three, because of the increased perceptual similarity between local features on the faces presented. The current experiment used stimuli that were not socio-motivationally relevant, but high task difficulty was nevertheless maintained through "switching" (term as described by Miyake et al., 2000) t-f-r colour as well as the relevance of the pre-cue so that cognitive demands would be similar in comparison to the previous experiments. Task difficulty was further manipulated by presenting sparse, versus crowded displays. On sparse displays (easy trials- where the target and distractor appear further apart) more resources were expected to be available for controlled processing due to decreased inter-stimulus competition; whereas on crowded displays (hard trials- where the target and distractor appear closer together) relatively fewer resources were expected to be available for controlled processing due to increased

inter-stimulus competition (see Hickey & Theeuwes, 2011; Gaspar & McDonald, 2014; Liesefeld et al., 2017 who reported that greater distance between target and salient distractor accelerated target identification).

The aims of experiment four were to uncover:

a) whether as was the case for experiment two, task performance would be maintained at the level of VWM processing, or whether a profile more consistent with Gaspelin and Luck's (2019) reactive suppression account would emerge when singleton search was performed under conditions where resources for cognitive processing were heavily taxed.

   If reactive suppression occured, this was expected to emerge as initial attentional capture (contralateral negativity) opposite both cued t-f-r inputs and non-cued distractor inputs during the early attention interval. During the late attention interval the early capture response would subsequently be suppressed. Evidence for improved controlled suppression for t-f-r inputs, versus non-cued distractor inputs would be provided if post-capture suppression was enhanced (increased P_D laterality divergence) opposite the cued t-f-r input, versus the non-cued distractor input.

   If reactive suppression did not occur because of high task demands in experiment four, then task performance was expected to be maintained in VWM by prevention (SP_D-sustained contralateral positivity), versus enhancement (SN_T- sustained contralateral negativity) of uploading and maintenance of the visual representation of respective distractor, versus target inputs. It was considered possible that the SP_D response would be enhanced for cued t-f-r representations, versus non-cued distractor representations.

b) Whether reduced available resources for cognitive processing on crowded, versus sparse displays would lead to diminished post-capture suppression for the former, versus the latter display type. This was expected to be evidenced if there was enhanced late attention PD laterality divergence opposite the cued t-f-r, versus non-cued distractor input for sparse, as compared against crowded arrays.

c) A further ERP component, namely the PPc, has been shown to index pre-attentive identification of salient featural discontinuities to facilitate subsequent controlled attentional deployment (Fontier-Gauthier et al., 2012; Leblanc et al., 2008). Evidence for early identification of the cue matching t-f-r would emerge as increased PPc laterality divergence on cued t-f-r trials versus non-cued trials. Evidence that PPc indexed early identification of t-f-r presence prepares controlled attention deployment would emerge if enhanced PPc laterality divergence on cued t-f-r trials were followed by enhanced reactive suppression of cued t-f-r inputs (PD opposite t-f-r input), versus non-cued distractor inputs (ND or reduced PD opposite non-cued distractors); whereas If PPc laterality diverged more on cued t-f-r trials than on non-cued trials, but this did not lead to more controlled reactive suppression for cued t-f-r inputs, versus non-cued distractors, this would suggest that PPc indexed early identification of t-f-r inputs does not lead to subsequent enhanced controlled attentional deployment.

5.4.1: *Behavioural findings*

Accuracy was lower and response times were slower on cued t-f-f, versus non-cued distractor trials. The finding suggests that saliency-driven factors drew attention toward inputs that matched the feature being maintained in VWM, even when performance would be impaired as a consequence. At the behavioural level, the data appears to reflect that “inhibition” (term as defined by Miyake et al., 2000) was impaired during experiment four because of the high cognitive demands as a result of template colour switching and monitoring for cue change (see Lavie et al.,

2004; Lavie, 2010 who showed impaired distractor inhibition was associated with increased cognitive load). Notably, the direction of behavioural effects did not significantly differ according to task difficulty as manipulated through display type (crowded vs. sparse). It will be of interest to uncover whether the consistency in behavioural performance was achieved through differential neurocognitive profiles for crowded, versus sparse displays on cued t-f-r, versus non-cued distractor trials.

Unexpectedly, lower accuracy and slower responses were associated with sparse, as compared against crowded displays. The opposite direction of effects was hypothesised because previous research found that increasing the distance between the search target and a salient distractor resulted in accelerated target identification speed (e.g., Hickey & Theeuwes, 2011; Gaspar & McDonald, 2014; Liesefeld et al., 2017). A possible explanation for the current data may be that for crowded display trials the focus of attention was small which could have facilitated attentional filtering and “inhibition” (term as described by Miyake et al, 2000). On sparse display trials attention may have been be more broadly distributed which could have increased task difficulty and thereby, diminished resources available for controlled attention processing. The associated neurocognitive profile of response will be examined and evidence for controlled processing differences between crowded, versus sparse arrays will clarify the direction of task difficulty change associated with array type.

5.4.2: *ERP findings*

5.4.2.1: *Ppc:* 80-120 ms

It was hypothesised that Ppc laterality divergence may be enhanced for cued t-f-r trials, versus non-cued distractor trials as previous work (Fortier-Gauthier et al., 2012) found that enhanced Ppc laterality divergence occurred on re-presentation of a previously displayed item. It

was of further interest to uncover whether this would also prepare and thereby facilitate controlled attention processing for cued t-f-r inputs, when compared against non-cued distractor inputs. The present data showed that Ppc laterality divergence was equivalent irrespective of whether colour of the search distractor was cued, or non-cued. The finding did not support the hypothesis that the Ppc would index preparation of attentional control networks for processing the t-f-r input. Thus, any subsequent neurocognitive evidence of improved controlled processing for cued t-f-r, versus non-cue distractors should be attributed to reactive suppression (if during late attention processing), or VWM uploading and maintenance (if during the sustained processing interval) and not to pre-attentive preparation of attentional control for t-f-r inputs.

5.4.2.2: *Attention intervals*

The previous experiments revealed that contralaterality divergence during early attention processing was equal irrespective of task, or stimulus salience. The data was interpreted as evidence that visual stimulus representations were automatically enhanced due to their intrinsic social and biological significance. It was further suggested that particularly high cognitive demands associated with increased task difficulty in experiment three may have been partially responsible for diminished controlled processing that was evidenced by the ERP findings. Experiment four used a paradigm that was cognitively demanding. Participants had to shift between six possible t-f-r colours and monitor for cue-change (positive (t-f-r cue) then negative (irrelevant cue) was grouped) which required shifting between task-sets ("shifting" as described by Miyake et al., 2000 heavily taxes cognitive processing resources). Lavie et al. (2004) and Lavie (2010) showed that increased cognitive demands diminished resources needed for distractor inhibition. It was of current interest to uncover whether it was the high cognitive load, or high socio-motivational salience associated with the previous paradigms that resulted in controlled processing being executed at the level of VWM, rather than during intervals associated with attention processing.

If for the current experiment controlled processing emerged during SPCN indexed VWM uploading and maintenance (sustained suppression, versus sustained selection for t-f-r and distractor inputs, versus target inputs, respectively) then this would suggest that cognitive load substantially influenced the profile of neuro-cognitive response associated with the previous experiments; however, if for the current experiment controlled processing emerged during the late attention interval following initial attentional capture for all inputs during early attention, then this would suggest that it was the high socio-motivational salience of the stimuli used for the previous experiments that was responsible for the profile of neuro-cognitive response that emerged.

5.4.2.2.1: *Early attention interval:* 134-168 ms

In contrast to the previous experiments that found attentional capture was equivalent for all lateral inputs, experiment four revealed that during the early attention interval, there was evidence for enhanced attentional capture for t-f-r and distractor inputs, when compared against target inputs.

It is possible that some amount of strategic early enhancement of visual representations with lateral gap position (denoted stimuli as distractors) may have served to facilitate subsequent goal-driven controlled processing for t-f-r and distractor inputs. Curiously, though the behavioural data showed slower and less accurate task performance for cued t-f-r, versus non-cue distractor inputs, this was not associated with an increased ND (distractor selection response) opposite cued t-f-r, versus non-cued distractor inputs. It is possible that the marginally smaller sample than desired (see methods section for details of power analysis for projected sample sample) may have resulted in a slightly underpowered analysis so that modulation of the early ND according to distractor type was not detected.

The early attention interval additionally revealed that irrespective of lateral stimulus type, there was increased attentional capture on sparse, versus crowded displays. Thus, in support of the behavioural results which were in the opposite direction to the hypothesised effects, the current data appear to support that controlled attention processing was diminished on sparse, as compared against crowded displays, resulting in increased attentional capture during the former, relative to the later array type. Further support for the current interpretation of the unexpected array type results would be provided if the proceeding late attention interval also finds decreased controlled goal-driven processing for sparse, versus crowded displays.

5.4.2.2.2: *Late attention interval:* 246-280 ms

On crowded arrays there was a contralateral positivity to (P_D indexed suppression of) lateral distractors, versus a contralateral negativity to (N_T indexed selection of) lateral targets. The direction of effects supports the presence of controlled goal-driven processing when items on the array appeared in close proximity. On sparse arrays there was a contralateral positivity to (P_D indexed suppression of) lateral distractors, that was significantly reduced to (less suppression of) lateral targets. The pattern of findings with respect to array type support the current interpretation that increased controlled goal-driven processing was associated with crowded, as compared against sparse array trials. It was not expected that target inputs would be suppressed on sparse display trials; however previous research found that target selection was actively terminated, rather than being left to passively fade (see Sawaki et al., 2012). One possible explanation for the current sparse array results may therefore be that automatic selection of the lateral stimulus during early attention processing was actively terminated during the late attention interval because adequate selective attention processing of the target had been achieved. Alternatively, if resources for controlled processing were diminished during sparse array search, then the distractor may have

captured and held attentional focus. Continued selection of the more salient midline positioned distractor could thereby have resulted in suppression of attention towards the less salient lateral target; though if the latter explanation were true, the response to the lateral target would likely be modulated according to whether the midline stimulus was a cued t-f-r, or non-cued distractor as the VWM match between the t-f-r and its preceding cue would presumably result in the t-f-r having higher salience, increasing its capacity to capture attention, when compared with the non-cued distractor. A final possibility may be that stimuli were processed according to position on sparse displays because processing based on attentional filtering was reduced when attention had further to travel between the more spatially distributed inputs. If the latter explanation were true, then during the late sustained processing interval (SPCN) further evidence for diminished goal-driven processing would be expected for target, versus distractor items on sparse, as compared against crowded array trials.

Increased top-down control for stimuli that appeared on crowded arrays likely occurred not only because attention could focus on a smaller spatial area, but also because the close presentation of these stimuli increased competition for attentional representation in visual cortex (see Desimone & Duncan, 1995). The current crowded array findings support deliberate and controlled suppression (P_D), versus selection (N_T) of distractor, versus target items, respectively. The sparse arrays findings do appear to reflect some degree of goal-driven influence as there was increased contralateral positivity divergence evoked by lateral distractors (P_D), versus lateral targets (N_D). However, the findings thus far support diminished controlled processing for sparse, versus crowded array trials.

Of crucial importance, in comparison to experiments two (neutral templates) and three (angry templates) which did not find evidence for controlled processing during the equivalent late

attention interval; when stimuli were colour singletons, the lateralised ERP response demonstrated controlled goal-driven processing in line with reactive suppression (see Gaspelin and Luck's, 2019 *reactive suppression account)*. This was despite the added pressure of "shifting" (term as described by Miyake et al., 2000) that was expected to heavily tax cognitive control resources during the current experiment. Notably though, the observed evidence for goal-driven attention processing was not modulated according to the relevance of the pre-cue as P_D laterality divergence was not significantly enhanced for cued t-f-r, relative to non-cue distractor inputs. A likely explanation is that when knowledge of a salient distractor feature was not gained through selection history experience, the t-f-r feature could not be used to facilitate *reactive suppression* of non-targets.

5.4.2.3: *SPCN interval:* 310-500 ms

The classical SPCN (sustained negative contralaterality) has been evidenced to reflect encoding and maintenance of stimulus representations in VWM and VSTM (see Dell'Acqua et al., 2006; Jolicoeur et al., 2006; Klaver et al., 1999; Vogel & Machizawa, 2004). Experiment two of the thesis revealed that in the absence of reactive suppression during the late attention processing interval, task performance was maintained through controlled prevention (SP_D- sustained contralateral positivity), versus enhancement (SN_T- sustained contralateral negativity) of VWM uploading and maintenance for respective t-f-r, versus t-f-s stimulus representations. In contrast, experiment four found that reactive suppression of t-f-r and distractor inputs was indexed by the presence of a P_D during the late attention interval. Regarding the current data, there was enhanced SPCN laterality divergence opposite target inputs, as compared against cued t-f-r and non-cued distractor inputs. Crucially, no evidence emerged for prevention of uploading and maintenance of distractor representations. The results indicate that reactive suppression during the previous late attention interval was adequate for task performance to be maintained at a sufficient level. As such

t-f-r and distractor representations did not require prevention from uploading and maintenance, as indexed by the profile of SPCN response.

5.4.2.3: *Summary of Discussion*

The data for experiment four appear to support previous findings (e.g., Beck et al., 2018; Cunningham & Egeth, 2016; Gaspelin & Luck, 2018; Moher & Egeth, 2012; Sawaki & Luck, 2010) which suggest reactive suppression occurs when a salient distractors feature cannot be predicted based on selection history (although the experiment four t-f-r colour feature was pre-cued, the colour itself switched between trials). In experiment four cognitive processing resources were heavily taxed and perceptual load was low as only two items appeared during search. It is possible that if perceptual demands had been higher, t-f-r utility may have increased despite the pre-cued colour feature switching between trials. Lavie et al. (2004) and Lavie (2010) showed that high perceptual demands resulted in increased suppression of non-targets. It was therefore, of further interest to uncover whether under the same cognitive load conditions as the current experiment four, increased perceptual demands could result in proactive suppression, as opposed to reactive suppression (terms as described by Gaspelin & Luck, 2019) of cued t-f-r inputs, in comparison to non-cue distractors. The proceeding final experiment of the series will aim to clarify whether a profile of behavioural response associated with proactive, or reactive suppression will emerge when perceptual load is high, even when cognitive processing resources are heavily taxed.

Chapter 6: Singleton templates-for-rejection with high perceptual difficulty

6.1: Introduction

Experiment four was a singleton search task. In groups of twenty consecutive trials participants were given a relevant cue (cued t-f-r trials) or irrelevant cue (non-cued distractor). The task heavily taxed cognitive processing resources as change of cue relevance had to be monitored for throughout the experiment. In addition, the colour feature of the cue switched between trials. The intention of experiment four was to uncover whether suppression of non-targets would occur during late attention processing (as appeared to be the case for similar published t-f-r findings, e.g., Beck et al., 2018; Cunningham & Egeth, 2016; Moher & Egeth, 2012), or during uploading and maintenance in VWM (as was case for experiment two). The experiment four findings were in-line with reactive suppression (term as described by Gaspelin & Luck, 2019), such that t-f-r and distractor inputs first received attentional selection processing prior to the attentional selection response being reactively suppressed during the late attention interval. Whilst the ERP profile associated with reactive suppression did not significantly differ between t-f-r and distractor inputs, the behavioural data revealed that there was significantly slower and less accurate task performance on cued t-f-r, relative to non-cued distractor trials. It was considered that the slightly lower sample than desired (see previous experiment power analysis for projected sample size) could have reduced the likelihood of finding significant corresponding ERP modulation between cued t-f-r and non-cued distractor inputs. Despite the issues around sample size for experiment four, the behavioural data clearly showed that prior knowledge of a distractors salient feature slowed rather than accelerated target search. The finding was in-line with previous published work which showed that switching t-f-r colour between trials was related to a t-f-r impairment (where t-f-r impairment refers to slower task performance when a search distractor matched, versus did not match the t-f-r colour).

Cunningham and Egeth (2016) randomly intermixed distractor-cue and no-cue trials, and also varied the distractor-cue colour during the experiment. The related behavioural data demonstrated no distractor-cue benefit to response times. In Moher and Egeth's (2012) paradigm both cue colour and cue relevance (relevant cue, versus irrelevant cue) were alternated between experiment trials. The

findings showed that target identification was impaired by the presence of a cue-matching distractor; however, when both location and colour of the distractor were known 800ms in advance, a relevant cue benefit did emerge (where relevant cue benefit refers to faster responses when a distractor in the array was preceded by a relevant, versus irrelevant cue). When a shorter 100ms post-cue delay was used, there was a relevant cue impairment for target identification speed. The authors subsequently proposed that a "search and destroy" mechanism actively seeks out cue matching distractors to facilitate later avoidance. By means of the search and destroy mechanism, pre-cued spatial location could be attended then avoided prior to target search on the longer post-cue delay trials. Using a similar paradigm, Beck et al. (2018) varied the colour of relevant and irrelevant cues between trials. Corresponding eye tracking data revealed that, in-line with Moher and Egeth's (2012) search and destroy mechanism, initial fixation on distractors which matched the relevant-cue, preceded avoidance of pre-cued distractors.

Contrasting findings to those of experiment four and the previous published research (Beck et al., 2018; Cunningham & Egeth, 2016; Moher & Egeth, 2012) were presented by Sawaki and Luck (2010) who demonstrated that when cue relevance and cue colour were maintained throughout experiment blocks, there was evidence for direct suppression of cue-matching non-targets. In Sawaki and Luck's (2010) paradigm participants searched for a highly salient distractor that did not share target features and that consistently appeared in red amongst an otherwise green display, or vice versa depending on experiment block. Fewer false positive responses were recorded compared to when a less salient distractor (same colour as the surrounding inputs) did share target features. Crucially, the associated ERP data revealed that a contralateral negativity (indicating attentional selection) was evoked by the target similar distractor; whereas a contralateral positivity (P_D) was evoked by the salient odd-colour-out (t-f-r) distractor during the same time-window. These findings formed the basis for the Signal Suppression Hypothesis (SSH) 'of controlled attentional capture' (Sawaki & Luck, 2010). According to the SSH the salient odd-colour-out distractor produced an early attend-to-me priority signal that was actively suppressed to prevent the capture of attention by salient, but task-irrelevant feature-matching inputs.

The SSH was since extended by Gaspelin and Luck (2019) to account for why some experiments (e.g., Sawaki & Luck, 2010; Sawaki & Luck, 2011), but not others (e.g., Cunningham & Egeth, 2016; Moher & Egeth, 2012; Beck et al., 2018) revealed direct distractor suppression without prior selection, versus distractor suppression only after prior selection, respectively. Gaspelin and Luck's (2019) 'proactive suppression' account was that repeated exposure to a distractor feature can reduce neuronal gain for specific feature values before stimulus onset in order to effectively reduce the processing of matching feature inputs without prior attentional selection. When a salient non-target feature can be reliably predicted, the salient signal can thereby be 'proactively suppressed'; whereas when a salient distractor feature cannot be reliably predicted, then analogous to Moher and Egeth's (2012) search and destroy mechanism, the distractor must first be selected before it is suppressed, a process the authors termed 'reactive suppression'.

A study by Arita et al. (2012) pre-cued the colour that would match the search target (target template), distractor (distractor template), or an irrelevant colour that would match neither the target, nor the distractor (irrelevant template) in separate experiment blocks. Crucially, the colour of the pre-cue switched between trials. The study found that target identification was faster on distractor template blocks, than irrelevant template bocks; though only for eight and twelve item search. On the four item display the target was identified at equivalent speed for negative and neutral blocks.

Initially the authors interpreted the findings as evidence that the pre-cued template colour had been dynamically used to either heighten (target template) or lower (distractor template) receptive cells response to inputs with the template matching feature. With similarities to Gaspelin and Luck's (2019) proactive suppression account, Arita et al's (2012) interpretation was posited as an extension to Neural Theory of Visual Attention (NTVA: Bundesen et al., 2005). Specifically, NTVA proposes that the mental image of a learned feature can dynamically influence the baseline firing of feature sensitive receptive cells. In particular, *Un-driven cell activity* (normal baseline firing of receptive cells) can combine with *inner driven cell activity* (visual memory representation influence on baseline firing of receptive cells) to

trigger a *baseline shift* (change to the receptive cells baseline firing rate) so that feature matching inputs receive heightened attentional weighting leading to preferential processing. By that account, *inner driven cell activity* could logically influence a *baseline shift* to decrease the baseline firing rate of feature sensitive receptive cells in order to down-regulate, or lower the attentional weighting and thus, decrease processing of inputs that match a known non-target feature. While Arita et al's. (2012) NTVA explanation could indeed account for their findings, it is also possible that participants employed a strategy whereby the pre-cued distractor colour was converted into a spatial cue. Because the target appeared in one of two colours that occupied separate halves of the search array, participants could have located the side of the array with the distractor colour, then quickly re-allocated their attention to search the opposite side. This would suggest that suppression of distractors in the Arita et al. (2012) study was not the result of feature matching inputs being deprioritised for processing, but was instead a reactive suppression process like the search and destroy mechanism proposed by Moher and Egeth (2012). A search a destroy mechanism would explain why a t-f-r benefit was seen when there were more stimuli on the array because serial search of the t-f-r group could have been avoided for eight and twelve item search, whereas for four item displays each colour group would likely have been searched using parallel processing. A final possible explanation for Arita et al's. (2012) data relates to Lavie et al's. (2004) Load Theory which proposes that while increased cognitive load diminishes distractor inhibition, increased perceptual load improves distractor inhibition. Thus, there remains the possibility that proactive t-f-r guided suppression may have occurred for the high perceptual load (eight and twelve item) displays, whereas reactive suppression may have been used on low perceptual load (four item) displays.

Because ERPs were not simultaneously recorded alongside behavioural responses in Arita et al's. (2012) study, the different explanations for the findings between the experiment blocks could not be tested. If the t-f-r was used to lower attentional weights when perceptual load was high, then under similar high perceptual load conditions t-f-r inputs could be proactively suppressed, even when the template feature has not been established through selection history learning due to t-f-r colour switching between trials. The previous experiment of this thesis could not clarify this possibility as search displays contained only two items and perceptual load was therefore, low. The final experiment

five of the current thesis will manipulate perceptual load to uncover whether proactive suppression can occur even when cognitive processing resources are heavily taxed due to a) cue relevance switching during experiment blocks (cue relevance will change every twenty trials) and b) t-f-r colour switching between trials.

For experiment five, six item search displays will present a distractor group and target group which will consist of three squares each (two coloured squares and one gray square in each group). The colour of the distractor group will be preceded by a relevant (cued t-f-r trial), or irrelevant (non-cued distractor trial) pre-cue which will be signaled by the appearance of a positive or negative sign adjacent to the pre-cue. For the high perceptual load block the gap on the target square will be small making its position (top or bottom of target square outline) difficult to locate. For the low perceptual load block the target gap will be large making its position comparatively easy to locate. Similar to experiments two to four, on each trial one group of squares will appear at above or below fixation position, and the other group will appear at left or right fixation position. The design was chosen so that the behavioural findings could be further investigated through a future follow-up ERP study. Due to constraints around lab use ERPs could not be concurrently recorded at the time that data was collected for experiment five.

A further factor that was investigated in experiment five was whether congruence between laterality of the pre-cue and cue-matching t-f-r group would effect use of the pre-cued feature. A search and destroy method of reactive suppression was proposed by Moher and Egeth (2012) as accountable for the emergence of a template-for-rejection benefit when both colour and location of non-targets were indicated 800ms in advance of the search array, though search and destroy appeared only to benefit reactive suppression in Moher and Egeth's (2012) experiment. The proposed experiment will not indicate whether the location of the pre-cue will match the location of the cued t-f-r, or non-cued distractor (due to a need to decrease the amount of information participants were expected to retain during trials). However, with respect to target search, Jonides (1981) found that even when cues were nonpredictive and targets were therefore, equally likely to appear at the cued, or un-cued location,

peripheral cues still triggered orienting of attention to the cued location. With respect to distractor suppression, Wang and Theeuwes (2018a) demonstrated that increasing the likelihood of distractors appearing at a particular location had the result of accelerating target identification speed on trials where the distractor appeared at the likely location, compared to the other locations. Wang and Theeuwes (2018a) further revealed that as the location of the distractor moved further away from the likely location, target identification speed was respectively augmented in-line with a distractor-gradient. Notably Wang and Theeuwes' (2018a) findings were based on selection history experience, such that the likely distractor location was the location where the search distractor appeared most often. Further published findings (Wang & Theeuwes, 2018b) showed that when likely distractor location was endogenously cued on a trial by trial bases the same benefit to target identification speed was not revealed. Though as previous research suggests features are encoded at receptive cells sensitive to the spatial location of items (e.g., Chun & Jiang, 1998; Kastner et al., 2007), it was of interest to explore whether congruency between location of the feature cue and the t-f-f input would facilitate template-guided reactive or proactive suppression in experiment five.

The aims of experiment five were to uncover:

Whether despite high cognitive task demands (due to switching the cued colour and monitoring for cue relevance change), behavioural responses will indicate proactive suppression of cued t-f-r inputs when perceptual load is high; this would be indicated if:

a) A t-f-r benefit is revealed for the high perceptual load condition. A t-f-r benefit would be confirmed if target identification is faster on cued t-f-r trials, as compared against non-cued distractor trials. As accuracy was also modulated by cue-relevance in experiment four, there may also be higher accuracy on cued t-f-r, versus non-cued distractor trials.

The low perceptual load condition is expected to correspond to a profile of behavioural response consistent with reactive suppression because controlled distractor suppression has been shown to diminish when perceptual load is low and cognitive load is high (see Lavie et al., 2004; Lavie, 2010). Furthermore, in experiment four (low perceptual load experiment) the ERP profile that indicated

reactive suppression (early attentional selection of non-targets followed by suppression during late attention processing) was associated with slower and less accurate target identification on cued t-f-r, versus non-cued distractor trials.

b) For the low perceptual load condition it is therefore, expected that reactive suppression will be indicated by slower and less accurate target identification on cued t-f-r trials, as compared against non-cue distractor trials.

c) If congruency between the location of the pre-cued feature and the t-f-r input facilitates controlled template-guided suppression then on the high perceptual load block, the t-f-r benefit should be further enhanced for congruent (pre-cue and t-f-r input presented in the same visual hemifield), as compared against incongruent (pre-cue and t-f-r input presented to opposite visual hemifield) trials. Congruency was not expected to modulate accuracy or speed of responses in the low perceptual load block because the basic t-f-r benefit (indicating proactive suppression) was not expected to emerge and could therefore, not be further facilitated by congruency between the location of the pre-cue and t-f-r input.

6.2: Methods

6.2.1: *Participants*

A statistical power analysis was performed for sample size estimation, with statistical values based on similar published research where a sample of N = 37 was used in a 2 x 2 repeated measures ANOVA (Vatterott, Mozer, & Vecera, 2018). The effect size and partial eta squared ($F = 7.75$, $\eta p^2 = .34$) was significant with an alpha and power of ($p < .05$, power = .80). These values were entered into a power analysis, but with the more conservative alpha and power values ($p < .001$, power = .95). The specified values generated a projected sample size of N = 18 (calculated using GPower 3.1.9.4). A sample size of N > 18 was therefore, sought for the purpose of the present 2 x 2 x 2 repeated measures ANOVA.

Thirty-one University of Roehampton students gave informed consent prior to participation and received course credit recompense. Ten participants were removed because Accuracy (Acc) in at least one condition fell below 70%. Of the remaining twenty-one participants (seventeen female), twenty were right-handed. Age ranged eighteen to forty-six (mean ± SD age = 21.24 ± 6 years) and all reported normal or corrected-to-normal vision. Normal colour-vision was confirmed through administration of the Ishihara tests for colour blindness. The experiment was performed in compliance with The University of Roehampton ethical and research guidelines and was approved by the University ethics committee.

6.2.2: *Stimuli and Apparatus*

Participants were seated in a darkened cubicle. A headrest was used to maintain a distance of 70 cm, from a 21-in. ViewSonic computer screen with 800 x 600 pixel display and a refresh rate of 75Hz, connected to a Dell precision Pentium IV computer. E-Prime Psychology Software 2.0 (Schneider, et al., 2002) was used for stimulus presentation and response collection. A purpose built

response box was used to collect Acc and response time (RT) feedback.

With respect to the cue-array, the stimuli were six (20 x 20 mm) coloured squares (blue: rgb (0,148,204), green: rgb (5,221,0), yellow: rgb (221,221,0), orange: rgb (221,88,0): red rgb (221,0,5), and violet: rgb (221,0,221)), that appeared against a dark grey background (rgb: 53,53,53). The squares each occupied one of six possible stimulus positions (counterbalance across trials), on the clockwise circumference on an octagon (radius 10mm), that appeared at the centre of the screen, prior to the onset of the squares. The centre of each coloured square, appeared 55 mm from the adjacent outer-edge of the octagon's six active segments, at clockwise visual angles: 50°, 90°, 130° and 230°, 270°, 310°, for left sided and right sided locations, respectively. The octagon appeared with eight visually differentiable segments; of which, seven segments were coloured light grey: rgb (191,191,191), in contrast to the *cue segment* which was dark grey: rgb (63,63,63) and contained a grey (rgb: 195,195,195), positive (+) or negative (-) symbol. On each trial, the *cue segment*, was overlaid on one of the six active segments, counterbalanced across trials. The active segments were defined by their positions, as each was clearly aligned with one of the six coloured squares that appeared at lateral left and right locations. The two inactive segments of the octagon, where those positioned along the centre (top and bottom) of the vertical midline with respect to the centre of the octagon. A plus symbol on the cue segment, indicated that the colour of the corresponding square, should be maintained in short term memory, for use on the proceeding search task. A minus symbol on the cue segment, indicated that the colour of the corresponding square was irrelevant and would therefore, not indicate the colour of either the distractor, or the target, on the proceeding search task.

The inter-stimulus interval (ISI) was defined by a grey (7mm x 7mm), central fixation cross (rgb: 195,195,195), against a dark grey background (rgb: 53,53,53), that remained on-screen from the start of the ISI, till offset of the proceeding search task. For the search task, six square outlines (squares were: 11 x 11 mm with outline thickness: 2 mm), appeared in two groups of three squares. The centre of the second square in each group, appeared 50 mm (4.1°), directly lateral to (left or right), or directly vertical to (above or below), the centre of the central fixation cross and square groups subtended 3.19° of visual angle. Of the six square outlines, five appeared with a gap missing from their

horizontal, left or right side (gap size: 5 mm), and one (the centre square within its group) appeared with a gap missing from its vertical, top or bottom side (gap size was 3 mm on the high perceptual load block, or 7 mm on the low perceptual load block). Following offset of the search display, the dark grey background remained on-screen during the inter-trial interval (ITI), after which, the octagon cue appeared again, which marked consecutive trial onset.

6.2.3: *Procedure*

A total of 560 trials (mean trial duration: 4.72ms) were divided into two experiment blocks (mean block duration: 22 minutes) with block order counterbalanced across participants; the high perceptual load block and low perceptual load block (280 trials per block) presented consecutive groups of 20 match trials followed by 20 no match trials, or vice versa, counterbalanced across participants.

Each trial began with the onset of the octagon cue for 160ms prior to the onset of the coloured cue squares (cue array) that remained on-screen for 300ms. Prior to beginning experiment trials, participants were informed that the colour of the square adjacent to a positive cue (match trial) indicated the colour of the square outline group that could be eliminated from their target search on the proceeding search display. It was made clear that the colour of the square adjacent to a negative cue (no-match trial) would not aid distractor elimination on the proceeding search display. Specifically, on match trials a template-for-rejection was provided, whereas on no-match trials no template-for-rejection was provided.

Offset of the cue array was directly proceeded by onset of the central fixation cross for 800ms before the search stimuli appeared. The fixation cross and search stimuli (search array) remained on-screen for 500ms and responses were collected up till 1,400ms post array on-set. With respect to the search array, target versus distractor stimuli appeared on the vertical midline (top or bottom), versus on the horizontal midline (left or right), or vice versa at equal probability, counterbalance across trials; however, only trials in which the distractor stimuli appeared on the horizontal midline, were selected for

analysis as congruency of the cue side to distractor side was of critical importance to the research question; specifically, congruent trials were those in which the colour cue and search distractors appeared on the same side of the screen (e.g. when a left sided cue preceded left sided distractors), whereas incongruent trials were those in which the search distractors appeared on the opposite side of the screen to that of the colour cue (e.g. when a left sided cue preceded right sided distractors).

In response to the search stimuli, participants were directed to report the position of the gap on the target- defined as the square outline with a gap missing from its top or bottom- using the first and second finger on their dominant hand and buttons one and two on the purpose built response box (button one for a top gap, button two for a bottom gap, counterbalance across participants). Following offset off the search stimuli, a blank screen appeared for ITI: 1450ms and 1650ms, after which the consecutive trial began. Every forty trials (3.14 minutes) participants received an automatic break wherein an onscreen message directed participants to press the space-bar when ready to continue experiment trials. Prior to high perceptual load and low perceptual load experiment blocks, participants received thirty-two practice trials with Acc and RT feedback that could be repeated until >70% Acc was achieved.

Figure 6.1

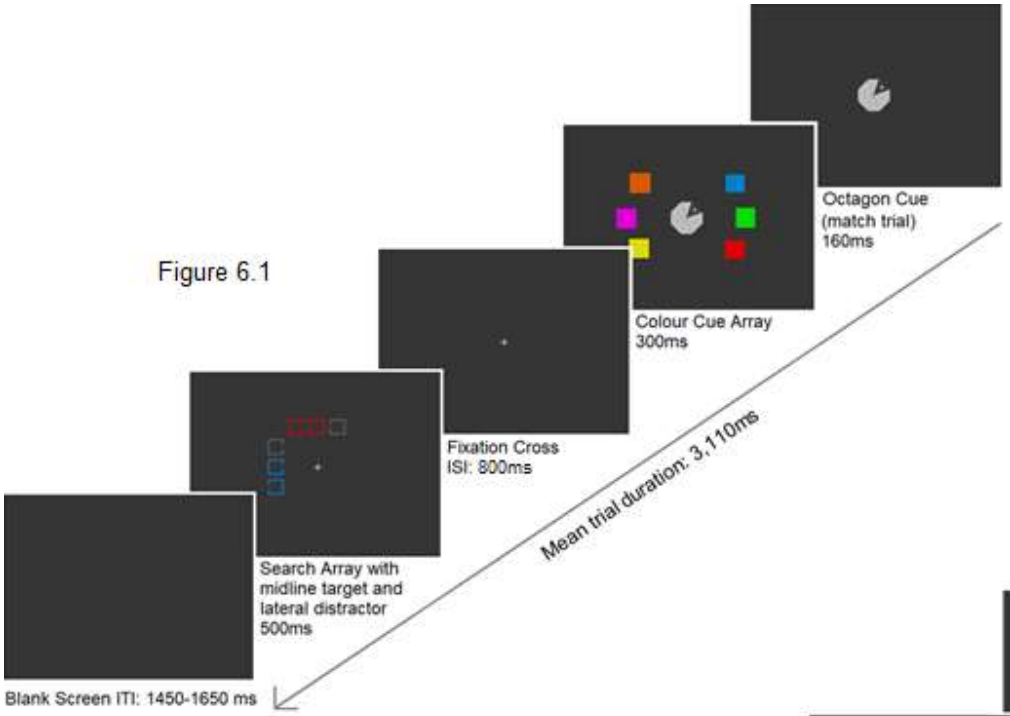


Figure 6.2

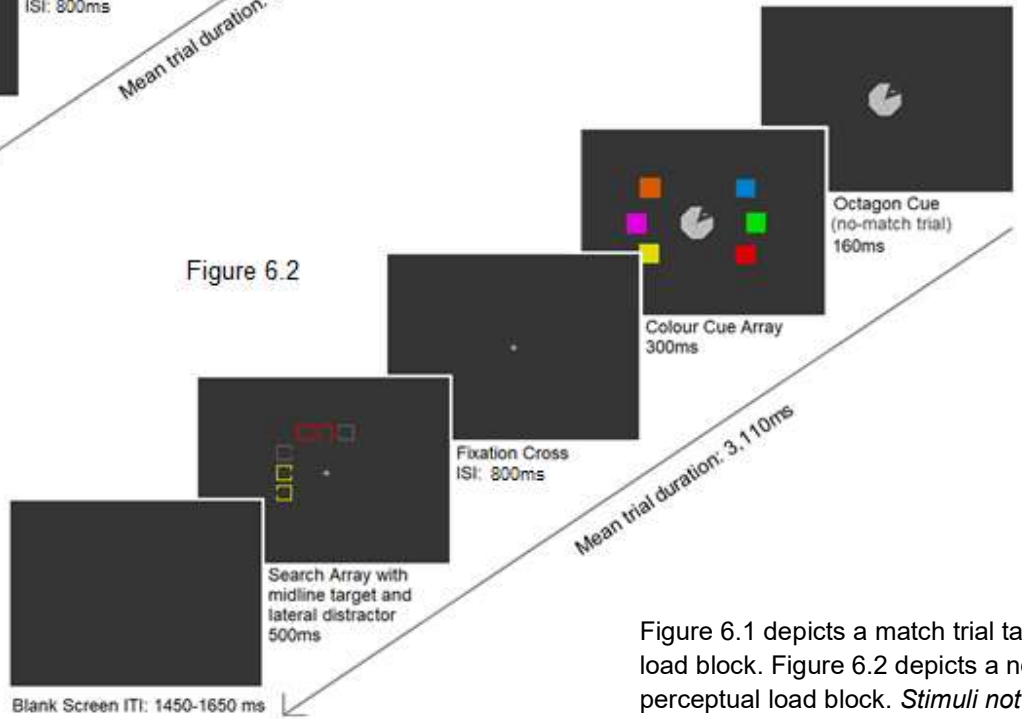


Figure 6.1 depicts a match trial taken from the high perceptual load block. Figure 6.2 depicts a no-match trial, taken from the low perceptual load block. *Stimuli not to scale.*

6.3: Results

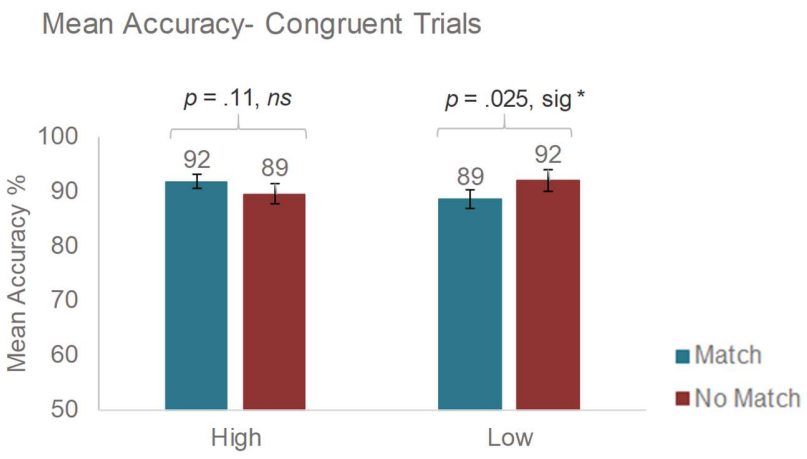
Non-responses and trials with response times (RTs) below 300ms were discarded; the subsequent mean and standard error of RTs for the sample was: *M* = 720.55 and *SEM* = 2.28, respectively. Mean percentage accurate responses (Acc) and mean correct response times (RTs) for each participant were entered into a three-way repeated measures analysis of variance (ANOVA) with the factors: trial type (valid distractor cue vs. invalid distractor cue), perceptual load (high vs. low) and congruence (congruent vs. incongruent). Where post-hoc t-tests were carried out, the Bonferroni correction for adjusted alpha level (.05/number of tests) was applied. Where Mauchley's test for the assumption of sphericity was violated, Greenhouse-Geisser corrected values were reported with degrees of freedom taken from sphericity assumed.

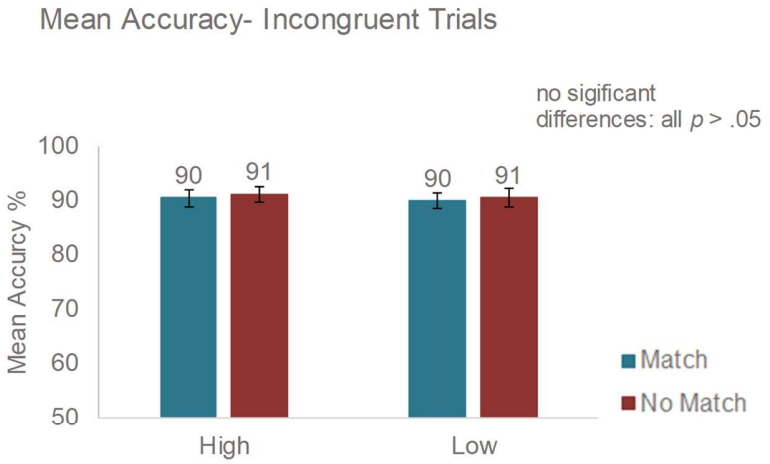
Match trials were those in which a positive symbol beside the pre-cue indicated that the colour of the pre-cue and of the distractor on the proceeding search display would match. No-match trials were those in which a negative symbol beside the pre-cue indicated that the colour of the pre-cue and of the distractor on the proceeding search display would not match.

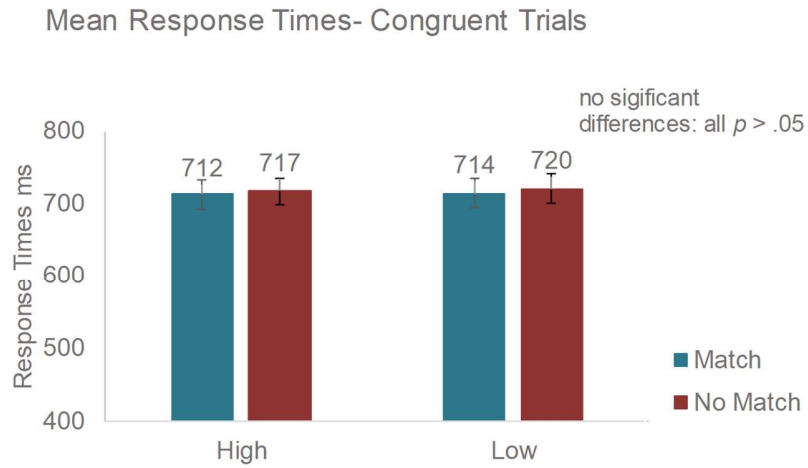
Congruent trials were those in which consecutive displays presented the pre-cue and distractor stimuli on the same side with respect to central fixation. Incongruent trials were those in which consecutive displays presented the pre-cue and distractor stimuli on opposite sides with respect to central fixation.

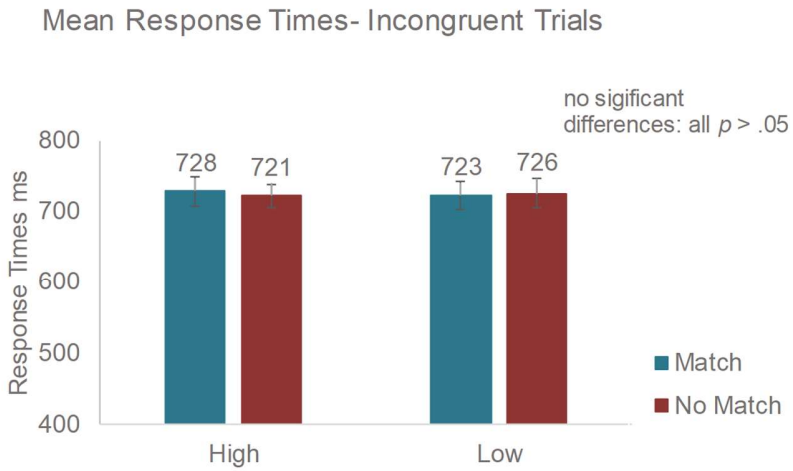
High load trials were those in which participants identified the position of a small gap on the target stimulus. Low load trials were those in which participants indicated the position of a large gap on the target stimulus.

Figure 6.3 (next page) depicts mean Acc (top panel) and mean RT (bottom panel) according to trial type: match (blue bars) and no match (red bars), congruency: congruent (left sided graphs) and incongruent (right sided graphs), and load: low load (right bars on each graph) and high load (left bars on each graph). Significant differences between conditions are indicated above the bars. Error bars represent standard errors for match and no-match trials.


Mean Accuracy- Congruent Trials
p = .11, ns
p = .025, sig *
Mean Accuracy %
100
90
80
70
60
50
92
89
89
92
High
Low
Match
No Match


Mean Accuracy- Incongruent Trials
no sigificant differences: all p > .05
Mean Accurcy %
100
90
80
70
60
50
90
91
90
91
High
Low
Match
No Match


Mean Response Times- Congruent Trials
no sigificant differences: all p > .05
Response Times ms
800
700
600
500
400
712
717
714
720
High
Low
Match
No Match


Mean Response Times- Incongruent Trials
no sigificant differences: all p > .05
Response Times ms
800
700
600
500
400
728
721
723
726
High
Low
Match
No Match

6.3.1: *Accuracy*

The ANOVA of mean accuracy scores uncovered no significant main effect of trial type, congruence, or perceptual load (all $F \leq 1$). No significant interaction effects were uncovered for trial type x congruence, or congruence x perceptual load (both $F \leq 1$); however, there was a significant two-way trial type x perceptual load interaction ($F(1,20) = 5.48$, $p = .03$, $\eta p^2 = .22$), that was subsumed under a three-way trial type x congruence x perceptual load interaction ($F(1,20) = 4.89$, $p = .04$, $\eta p^2 = .2$). Subsequent two-way ANOVAs with the factors: trial type x perceptual load were executed separately for congruent and incongruent trials.

The ANOVA of congruent trials, uncovered no main effect of trial type, or perceptual load (both $F \leq 1$); however, there was a highly significant two-way trial type x perceptual load interaction ($F(1,20) = 9.35$, $p = .006$, $\eta p^2 = .32$). Post-hoc t-tests with Bonferroni adjusted alpha level of .025 per test (.05/2) compared match, versus no match trials separately for perceptual load: high then low.

High perceptual load corresponded to higher accuracy on match ($M = 91.72\%$, $SEM = 1.25$), versus no match trials ($M = 89.44\%$, $SEM = 1.89$), although the direction of effects failed to reach significance ($t(20) = 1.68$, $p = .1$, *ns*).

Contrastingly, low perceptual load corresponded to significantly lower Acc on match, versus no match trials (respective means of: $M = 88.6\%$, $SEM = 1.78$ and $M = 91.92\%$, $SEM = 1.89$, $t(20) = -2.42$, $p = .025$).

The ANOVA of incongruent trials, uncovered no main effect of trial type, or perceptual load and the trial type x perceptual load interaction was non-significant (all $F \leq 1$).

6.3.2: *Response Times*

The ANOVA of mean response times, uncovered no main effect of trial type, congruence, or perceptual load (all $F \leq 1$). No two-way interaction effects were observed for trial type x congruence, trial type x perceptual load, or congruence x perceptual load (all $F \leq 1$) and the three-way trial type x congruence x perceptual load interaction was non-significant ($F < 1$).

6.3.3: *Results Summary*

6.3.3.1: ***Response Times***

Target identification speed was not significantly affected by any of the experiment manipulations.

6.3.3.2: ***Accuracy***

When laterality of the distractor and template-for-rejection were congruent, the direction of mean accuracy was different between the low and high perceptual load conditions. Low perceptual load (large target gap) corresponded to lower accuracy when a template-for-rejection was, versus was not provided. Contrastingly, high perceptual load (small target gap), corresponded to higher accuracy when a template-for-rejection was, versus was not provided; however the latter comparison was not statistically reliable as the threshold for statistical significance was not reached.

6.4: Discussion

Experiment five aimed to uncover whether a t-f-r benefit indicating proactive suppression would occur under conditions of high perceptual load despite high cognitive task demands as a result of a) switching the colour feature of the pre-cue and b) participants being required to monitor the cue screen for change in cue relevance. Profiles of behavioural response indicating proactive, versus reactive suppression were expected for respective high (small target gap), versus low (large target gap) perceptual load conditions in experiment five because Lavie et al. (2004) and Lavie (2010) found evidence of improved distractor suppression for tasks in which perceptual load was high. Additionally, Arita et al. (2012) revealed a t-f-r benefit for eight and twelve, but not four item search. While Arita et al's. (2012) findings may have been due to change in search strategy as a result of participants converting colour feature cues into spatial cues, it was considered in the introduction to experiment five that feature-guided suppression may have been facilitated when search was executed under high (eight and twelve item search), but not low (four item search) perceptual load in Arita et al's. (2012) paradigm.

In the current high perceptual load condition, a t-f-r benefit indicating proactive suppression was expected to be confirmed by faster and more accurate target identification on cued t-f-r trials, as compared against non-cued distractor trials. In the current low perceptual load condition, a profile of behavioural response consistent with reactive suppression was expected to be indicated by slower and less accurate target identification on cued t-f-r trials, as compared against non-cue distractor trials.

Congruency between the pre-cue and t-f-r input was also expected to modulate behavioral performance as previous published findings (Wang & Theeuwes, 2018a, 2018b) suggested location could become a t-f-r as indicated by faster target identification when a distractor was presented at a location where previous distractor inputs had more frequently appeared. Although Wang & Theeuwes (2018b) found endogenous cues (as

opposed to the previous selection history learning) were not associated with a location based t-f-r benefit, other work suggests features are encoded at receptive cells sensitive to the spatial location of items (e.g., Chun & Jiang, 1998; Kastner et al., 2007). It was therefore, considered possible that proactive suppression of the cued t-f-r input could be further facilitated when the pre-cue and t-f-r input appeared in the congruent visual hemifield. Thus, a congruency benefit was expected on high, but not low perceptual load trials because proactive suppression was expected for the former, but not the latter condition. The congruency benefit was expected to emerge as more accelerated target identification for t-f-r, versus distractor inputs, on congruent, as compared against incongruent trials.

The results from experiment five revealed that on congruent trials, there were different patterns of task accuracy associated with low (easy to locate targets), versus high (hard to locate targets) perceptual load. Low perceptual load corresponded to a t-f-r impairment, as response accuracy was lower on relevant, versus irrelevant cue trials. In contrast, high perceptual load was associated with a t-f-r benefit, as response accuracy was higher on relevant, versus irrelevant cue trials, although unfortunately the latter difference did not reach statistical criterion for significance.

It is possible that if the experiment had employed only the high perceptual load task, a significant template-for-rejection benefit would have emerged. This is because exposure to the low perceptual load task may have influenced the processing strategy that participants used. Because sample size was low block order could not be included as a factor in the analysis so it was not possible to determine if the t-f-r benefit for the high perceptual load block would have been significant when participants received the high perceptual load block prior to the low perceptual load block. In addition, the use of relatively short blocks may not have allowed enough time for participants to develop an

optimal search strategy in the high perceptual load task. Short blocks were used to prevent participant fatigue resulting in diminished cognitive control.

The current results showed no effect of cue-relevance (cued t-f-r vs. non-cued distractor trials) or perceptual load (high vs. load) when the pre-cued colour feature and non-target inputs (t-f-r and distractor) appeared in the opposite hemifield (incongruent trials). The finding suggests that congruency may influence pre-cue utility, but this may simply not have been observed using behavioural measures alone. It is also possible that if the pre-cue and non-target inputs had more frequently appeared in the congruent visual hemifield, a significant colour feature-driven t-f-r benefit may have emerged for the high perceptual load block. Recent work (Wang & Theeuwes, 2018a, 2018b) demonstrated that statistical regularities with respect to the probability that a salient distractor would appear at a particular location facilitated distractor suppression, and other published findings (e.g., Chun & Jiang, 1998; Kastner et al., 2007) suggest that feature sensitive receptive cells were also sensitive to spatial location. Taken together, the published findings (Chun & Jiang, 1998; Kastner et al., 2007; Wang & Theeuwes, 2018a, 2018b) suggest the possibility that the use of encoded features as t-f-r could be further enhanced when the spatial location of the t-f-r input is congruent with the spatial location where the t-f-r feature was encoded and this benefit could be enhanced through statistical learning that the location of the encoded t-f-r feature will likely be congruent with the location where the encoded feature will appear as a distractor. A future study could explore this possibility.

Other published findings (Bretherton et al., 2017; Beck et al., 2018; experiment two of the current thesis) showed that end-of-trial manual responses did not always demonstrate consistency with observed modulation of the neurophysiological response; therefore, it is possible that had ERPs been simultaneously recorded during experiment five, a neurophysiological profile of response consistent with proactive, versus reactive

suppression for the high, versus low perceptual load blocks may have been observed for congruent trials. Due to constraints on lab use concurrent recording of ERPs was not possible. Further to the issues discussed with respect to the accuracy findings, experiment five found that speed of target identification was not significantly modulated by any of the experiment factors. Whilst findings of a t-f-r benefit have not always been based on response times (e.g., Sawaki & Luck, 2010 referred to number of false positive responses between experiment conditions), other published t-f-r work did find modulation of response times for t-f-r, versus normal distractor trials (e.g., Arita et al., 2012; Moher & Egeth, 2012; Woodman & Luck, 2007). It is possible that with a larger sample and increased block length, modulation to response times between the current experiment factors may have been revealed. The current findings could not resolve whether Arita et al's. (2012) results occurred due to enhanced suppression on high (eight/twelve item search), versus low (four item search) perceptual load blocks, or because participants converted feature cues into spatial cues. A follow up experiment with increased participants numbers and block order included as a factor should analyse both behavioural and ERP data to elucidate if proactive suppression can occur under high cognitive task demands if perceptual load is sufficiently high.

Chapter 7: General Discussion

Figure 7.1 Summary of main hypotheses and findings for experiments 1-5:		
Chapter & Experiment- **Brief paradigm description:**	**Main hypotheses:**	**Main Findings:**
Chapter 2- Experiment 1: Bilateral displays contained a neutral or angry t-f-r or t-f-s (depending on experiment block). Accuracy and speed of target identification was collected alongside ERPs measures.	**1)** The impact of emotionally salient distractor stimuli when angry, versus neutral valence was a t-f-s. a) An N2pc, followed by a P_D to template-matching targets would indicate attentional selection, followed by active termination of attentional selection to template-matching targets (see Liesefeld et al., 2017; Sawaki et al., 2012). b) An N2pc that gradually attenuates would indicate that template-matching targets were allocated enhanced processing resources, encouraging maintenance of attentional selection towards stimuli containing the template-matching feature (see Bundeson, 1995; Bundeson et al., 2005).	**Neutral template blocks:** The behavioural findings revealed faster and more accurate task performance for neutral t-f-r, versus t-f-s blocks, suggesting it was easier to ignore, than attend to neutral valence when emotional valence competed for attention. **Neutral t-f-s:** The ERP findings appeared to show that attention was initially captured by the emotional distractor stimulus (N2pc opposite the emotional distractor), but that the early attentional capture response was then suppressed (P_D opposite the emotional distractor) and the neutral target selected (N_T opposite the neutral target), as reflected by the N2pc flip that was observed in the ERP profile of

	2) The impact of emotionally salient target stimuli when angry, versus neutral valence is utilised as a t-f-r. a) A P_D contralateral to template-matching distractors would be in line with Sawaki and Luck's (2010) SSH, demonstrating active suppression of the template-matching distractors "attend-to-me" priority signal. b) An 'N2pc flip' (term used by Jannati, et al., 2013; Liesefeld et al., 2017; McDonald et al., 2013; Woodman & Luck, 1999) that is first contralateral to template-matching distractors, then contralateral to emotional valence targets would be in-line with post-capture neural dynamics reported by Liesefeld et al. (2017), showing that template-matching distractor features first capture attention before capture is actively suppressed and attention redeployed to the target.	response for the experiment one neutral t-f-s condition. **Neutral t-f-r:** Because experiment one used a bilateral array, it was not clear whether the findings showed: • proactive and continued suppression of the neutral t-f-r input (early P_D opposite the neutral t-f-r that was actively maintained throughout the attention epoch), or • early attentional capture by the more salient emotional face (overwhelming N_T contributions to the observed N2pc opposite the emotional target) that was not subject to subsequent suppression because on neutral t-f-r trials the

		more emotional stimulus was also the search target. **Angry template blocks:** The behavioural findings revealed faster and more accurate task performance for angry t-f-s, versus t-f-r blocks, suggesting it was easier to attend to, than ignore angry valence. No significant ERP laterality divergence emerged for the angry t-f-s or t-f-r conditions, possibly because attention was rapidly and repeatedly pulled between the highly salient and more perceptually similar (as compared with the neutral template condition) emotional faces.

Chapter 3- Experiment 2: Sparse displays were used to isolate the lateralised ERP response to the evoking stimulus. Neutral valence was the t-f-r or t-f-s (depending on experiment block). Accuracy and speed of target identification was collected alongside ERPs measures.	**3)** The impact of emotionally salient distractors when neutral valence was a t-f-s. c) For the neutral t-f-s condition attentional capture by emotional distractors during the first attention interval (134-180ms) was expected to emerge as a significant contralateral negativity (N_D) opposite emotional distractors, in comparison to that recorded for neutral t-f-s (significantly smaller N_T laterality divergence). Attentional capture by emotional distractors was expected to be subsequently suppressed (contralateral positivity (P_D) opposite the emotional distractor stimulus) to allow neutral t-f-s to be selected (contralateral negativity (N_T) opposite the neutral t-f-s) during the second attention interval (230-260ms). The pattern of effects was expected to provide confirmatory support for the interpretation of neutral t-f-s findings in the previous experiment one.	**Behaviour:** Speed and accuracy of target identification did not significantly differ between the neutral t-f-r and t-f-s conditions. **ERPs:** Attentional capture was observed during the early attention interval, irrespective of task-goals. During late attention processing there was a significant contralateral negativity for emotional target inputs (midline t-f-r trials) only. Although there was no evidence of reactive suppression during late attention processing, the ERP data revealed that during the SPCN interval, there was a sustained contralateral positivity for neutral t-f-r and emotional distractor inputs, versus a sustained contralateral negativity for neutral t-f-s and emotional target inputs. As the SPCN has been implicated in uploaded and maintenance of visual

	4) Whether the ERP profile of response for the experiment one neutral t-f-r condition was driven by: d) proactive and continued suppression of the neutral t-f-r input. The presence of a significant contralateral positivity (P_D indexed suppression) opposite the laterally presented neutral t-f-r would indicate controlled proactive template-guided suppression. e) early attentional capture by the more salient emotional face. The presence of a contralateral negativity that is larger opposite the emotional target (N_T) than opposite the neutral t-f-r (N_D) would indicate that attention was captured by the more salient (emotional target) input resulting in diminished resources for processing the less salient neutral t-f-r input. **5)** Based on the findings of previous research (Feldmann-Wüstefeld & Vogel, 2019; Holmes et al. 2009; Jannati et al. 2013) it was of interest to explore if the SPCN component may, like the N2pc and CDA components, also reflect the sum of	representations in WM, the finding suggests that continued engagement and VWM maintenance of face stimuli was enhanced, or prevented according to task-goals.

	multiple sub-components. If the SPCN can both enhance and prevent uploading and continued engagement with the visual representation of search items in VWM in line with task goals, then this was expected to be reflected by a sustained contralateral positivity, versus negativity opposite neutral t-f-r, versus t-f-s inputs. **6)** In-line with the experiment one findings, the high socio-motivational salience of the emotional faces, in comparison to neutral template faces was expected to be associated with faster and more accurate task performance for neutral t-f-r, versus t-f-s blocks.	
Chapter 4- Experiment 3: Sparse displays were used to isolate the lateralised ERP response to the evoking stimulus. Angry valence was	**7)** In-line with the experiment one findings, the high socio-motivational salience of angry valence was expected to correspond to faster and more accurate responses for the angry t-f-s, versus t-f-r blocks. **8)** Because controlled attention processing appeared diminished	**Behaviour:** Faster and more accurate target identification was associated with angry t-f-s, as compared against t-f-r blocks. **ERPs:** Early attentional capture was equivalent, irrespective of task-goals or stimulus type (angry

the t-f-r or t-f-s (depending on experiment block). Accuracy and speed of target identification was collected alongside ERPs measures.	during the angry template conditions in experiment one it was expected that there would more saliency-driven than goal-driven contributions to the ERP profile of response in experiment three. As such, an enhanced contralateral negativity (attentional selection) was expected for angry template-matching inputs, versus other emotion inputs during the early and late attention intervals irrespective of task-goals. As the previous experiment two found evidence of controlled processing during the late sustained processing (SPCN) interval, it was expected that there would be a sustained contralateral negativity (SN_T) opposite angry t-f-s inputs, versus a sustained contralateral positivity (SP_D) opposite angry t-f-r inputs, showing that task performance could be maintained outside typical attention stages through controlled processing at the level of VWM uploading and maintenance.	template/other emotion). During the late attention processing interval, statistically significant laterality divergence was not revealed. The SPCN interval findings showed that the visual representation of angry template inputs corresponded to enhanced uploading and maintenance in VWM, as compared against the other emotion inputs. Further modulation according to whether angry valence was a t-f-s, or t-f-r was not revealed.

Chapter 5- Experiment 4: Participants searched two item arrays and reported the gap position on a colour singleton target. The colour of the non-target singleton was preceded by a relevant, or irrelevant pre-cue. Items appeared close together (crowded array) or far apart (sparse array). The relevance of the pre-cued colour switched every twenty trials throughout the experiment. The colour	**9)** whether goal-driven processing would occur at the level of VWM processing (as was found for experiment two), or whether a profile more consistent with Gaspelin and Luck's (2019) reactive suppression account would emerge when singleton search is performed under conditions where resources for cognitive processing are heavily taxed. e) reactive suppression was expected to be supported if initial attentional capture (contralateral negativity) emerged opposite both cued t-f-r inputs and non-cued distractor inputs during the early attention interval. During the late attention interval the early capture response would subsequently be suppressed. Evidence for improved controlled suppression for t-f-r inputs, versus non-cued distractor inputs would be supported if suppression were enhanced (increased P_D laterality divergence) opposite the cued t-f-r input, versus the non-cued distractor input. f) If reactive suppression did not occur because of high task	**Behaviour:** slower and less accurate target identification was revealed for cued t-f-r, versus non-cued distractor inputs. **ERPs:** The profile of response indicated reactive suppression as cued t-f-r and non-cued distractor inputs received early N_D indexed attentional selection followed by P_D indexed suppression during late attention processing. For the SPCN interval, sustained selection was not prevented, but was instead reduced (decreased contralateral negativity laterality divergence) for cued t-f-r and non-cued distractor inputs, when compared to target inputs. **Crowded versus Sparse arrays:** In contrast to previous findings, faster and more accurate task performance was recorded on crowded, versus

indicated by the pre-cue switched between trials.	demands in experiment four, then task performance was expected to be maintained in VWM by prevention (SPD-sustained contralateral positivity), versus enhancement (SNT- sustained contralateral negativity) of uploading and maintenance of respective distractor, versus target representations. A possible enhanced SPD response for the cued t-f-r, versus non-cued distractor representation would suggest that feature templates can be used to facilitated controlled VWM processing when, in contrast to the stimuli used for experiment two, visual inputs have equivalent salience. **10)** Proactive suppression of cued t-f-r, versus non-cued distractor inputs was not expected due to switching the template feature between trials and changing cue relevance every twenty trials; therefore, in-line with previous reactive suppression findings (e.g.,Moher & Egeth, 2012), equivalent, or slower and less accurate target identification was expected for cued t-f-r,	sparse displays. ERPs revealed evidence for better attentional control on crowded versus sparse displays. The findings suggest that crowded arrays were easier to process than sparse arrays because attention resources could be focussed on a smaller area for the former, versus latter array type, respectively.

	versus non-cued distractor inputs. **11)** Target and distractor inputs were position in close proximity (crowded array), or far apart (sparse array). It was expected that the experiment four findings would be in-line with previous research (e.g., Liesefeld et al., 2017) showing faster RTs when a salient distractor appeared further from the search target. The profile of ERP response was also explored.	
Chapter 6- Experiment 5: The colour of the non-target group (three closely positioned squares (one gray/two same coloured) was preceded by a relevant, or irrelevant pre-cue. As with experiment four, the relevance of the pre-cued	**12)** Whether despite high cognitive task demands (due to switching the cued colour and monitoring for cue relevance change), behavioural responses would indicate proactive suppression of cued t-f-r inputs when perceptual load is high. This would be supported if a t-f-r benefit is revealed for the high perceptual load condition. A t-f-r benefit would be confirmed if target identification were faster and more accurate on cued t-f-r trials, as compared against non-cued distractor trials.	**Congruent trials:** Low perceptual load was associated with a t-f-r accuracy impairment as significantly less accurate target identification was revealed for cued-t-f-r, versus non-cued distractor trials. High perceptual load was associated with more accurate target identification on cued-t-f-r, versus non-cued distractor trials, though the direction of

colour switched every twenty trials throughout the experiment and the colour indicated by the pre-cue switched between trials. Gap position on a single target (target group comprised three squares- one gray/two same coloured) was indicted by participants. Perceptual load was also manipulated. A small, versus large target gap was used for the respective high, versus low perceptual load block.	**13)** The low perceptual load condition was expected to correspond to a profile of behavioural response consistent with reactive suppression because in experiment four where perceptual load was low (two item search) the ERP profile indicated reactive suppression. This corresponded to slower and less accurate target identification on cued t-f-r, versus non-cued distractor trials. As such, for the low perceptual load condition it was predicted that reactive suppression would be indicated by slower and less accurate target identification on cued t-f-r trials, as compared against non-cue distractor trials. **14)** Congruency between the visual hemifield to which the pre-cued feature and the t-f-r input were presented, was expected to facilitate proactive suppression on the high perceptual load block. This was expected to emerge as an enhanced t-f-r benefit for congruent (pre-cue and t-f-r input presented in the same visual	accuracy difference did not reach statistical significance; therefore proactive suppression could not be supported. Speed of target identification was not modulated by the experiment conditions. **Incongruent trials:** Speed and accuracy of target identification was modulated by none of the experiment conditions.

	hemifield), versus incongruent (pre-cue and t-f-r input presented to opposite visual hemifield) trials.	

7.1: Discussion

Experiment one hypothesised that t-f-r inputs would either be proactively suppressed, or would capture attention before active suppression of the attentional capture response. It was further hypothesised that t-f-s inputs would receive attentional selection processing followed by either active termination or gradual attenuation of the selection response. The ERP data on the neutral t-f-s block revealed a profile of response consistent with attentional capture by the most socio-motivationally salient item, followed by late selection of the neutral t-f-s; whereas neutral t-f-r inputs appeared to be actively and continuously suppressed; though what emerged as neutral t-f-r suppression may more plausibly have been early capture and continued selection of the more socio-motivationally salient input. For angry template conditions, the ERP data showed that neither of the bilaterally presented faces received statistically identifiable attentional selection, likely because attention was rapidly and repeatedly pulled between the emotional inputs. What is more, behavioural responses were faster and more accurate on neutral t-f-r, versus t-f-s, and angry t-f-s, versus t-f-r blocks which strongly supports that the most socio-motivationally salient stimulus received attentional prioritisation irrespective of task-goals. The findings were not in the direction that was hypothesised. Exogenous saliency-driven processing was more dominant than expected. A likely explanation for the deviation between the hypothesised effects and the actual findings relates to the limitation that the pattern of ERP response hypothesised was based on the findings of singleton search studies (e.g., Bundeson, 1995; Bundeson et al., 2005; Jannati, et al., 2013; Liesefeld et al., 2017; McDonald et al., 2013; Sawaki & Luck, 2010; Sawaki et al., 2012; Woodman & Luck, 1999). To date, very little published research has focussed on guidance of attention by templates with socio-motivational relevance. One published study (Bretherton et al., 2017) that did investigate whether attention could be controlled to avoid attentional capture by inputs with socio-motivational salience used covertly rather than overtly defined template faces (participants were not explicitly told to

ignore face inputs, but the target was always a singleton stimulus. The simultaneously presented face never had target status). Bretherton et al. (2017) revealed that emotional face t-f-r inputs could not be proactively suppressed, but during a post-stimulus interval associated with late attention processing, there was evidence for suppression of the early attentional capture response. With respect to experiment one of the current thesis, the ERP response on the neutral t-f-s condition showed a similar profile to that reported by Bretherton et al. (2017) as the more socio-motivationally salient stimulus (emotional distractor) appeared to first capture attention before the attentional capture response could be suppressed so that attention could be allocated to the less salient neutral t-f-s. It would be reasonable to assume that inputs which match templates with socio-motivational salience (emotionally relevant inputs) may be processed differently to inputs which match singleton feature templates; especially as a number of studies have reported evidence for attentional prioritisation of emotion (e.g., Holmes et al., 2005; Eastwood, Smilek, & Merikle, 2003; Fox et al., 2001). Thus, some divergence would be expected between the experiment one hypotheses that were based on singleton paradigm findings and the actual results which were based on a paradigm that used socio-motivationally salient stimuli. The current findings demonstrate that socio-motivationally relevant search templates may not be subject to the same attentional control settings as would be expected for singleton search templates. While salient singleton distractors that match a selection history learned t-f-r feature may be proactively suppressed (see Gaspelin & Luck's, 2019 proactive versus reactive suppression account) so that attentional capture is actively prevented; socio-motivationally salient distractors may not be subject to proactive suppression, but may instead be reactively suppressed, such that they first capture attention before the attentional capture response can be subsequently suppressed. This contributes to understanding how search templates may function with respect to real world inputs.

Experiment two isolated the ERP response to the lateral stimulus (achieved by presenting one stimulus directly above or below central fixation so that the other stimulus could appear alone at lateral left or right location) so that the interpretation of the experiment one neutral template findings could be confirmed. The method of clarification was chosen because findings from previous ERP paradigms have been clarified by comparing the data from unilateral sparse displays (item one above or below and item two left or right of fixation) with data from bilateral displays (target and distractor occupy opposite sides of display) (see Hickey et al., 2009 and Liesefeld et al., 2017). It was expected that the previous neutral t-f-r findings could be clarified with respect to whether the profile of ERP response showed saliency-driven attentional capture and continued selection of the emotional face, or controlled proactive and continued suppression of the neutral t-f-r. Isolation of the lateralised ERP response to the evoking stimulus was also expected to confirm that on the neutral t-f-s block, the emotional face had first captured attention before attentional capture was suppressed so that the neutral t-f-s could be attended. The findings for experiment two unexpectedly revealed a largely different pattern of effects than had been hypothesised. Speed and accuracy of target identification was equivalent between the neutral t-f-r and t-f-s conditions, suggesting inter-stimulus competition effects may have differed between experiment one and two. Further to this, the profile of ERP response for experiment two revealed that attention was initially captured to the same extent, irrespective of whether the lateral face was a neutral t-f-r versus t-f-s, or an emotional target (midline t-f-r trials) versus distractor (midline t-f-s trials). Attentional capture was not subsequently suppressed for neutral t-f-r and emotional distractor inputs. Instead, the late attention interval revealed significant laterality divergence (indicating attention selection) for the lateral emotional target only. No significant laterality divergence was revealed for the other face inputs. The findings appear to support that in the experiment one neutral t-f-r condition, what emerged as continued suppression of the neutral t-f-r was more likely continued selection of the more salient emotional target without the need for the neutral t-f-r to be actively suppressed.

The late attention findings for experiment two suggest that, contrary to Sawaki et al's. (2012) findings which revealed active termination upon completion of singleton target selection, early attentional capture by the neutral t-f-r passively faded. This implies reduced controlled attention processing for stimuli with socio-motivational relevance, when compared against singleton stimuli.

In contrast to the early attention findings in experiment two, early attentional capture was not equivalent between the neutral template and emotional face stimuli in experiment one. The most plausible interpretation for the divergence in results may be that inter-stimulus competition was greater for bilateral (experiment one), as compared with unilateral (experiment two) displays. Previous work has shown that stimuli presented on the vertical midline may be processed differently to laterally presented stimuli, especially when midline stimuli appear above central fixation (see Hickey et al., 2009; Luck, Girelli, McDermott, & Ford, 1997); this is because the spatial position of visual inputs map on topographically representative areas in visual cortex. Bilaterally presented items likely mapped onto and thus competed for representation in ventral processing streams; whereas midline, versus lateral located items on unilateral displays likely mapped onto respective dorsal and ventral networks, resulting in reduced inter-stimulus competition.

The experiment one findings were in-line with controlled goal-driven processing during late attention; whereas in experiment two there was no evidence of controlled processing during the equivalent late attention interval. For experiment two goal-driven processing took place during the proceeding late sustained processing interval known as the SPCN (sustained posterior contralateral negativity). Some evidence of task-related SPCN modulation was hypothesised in experiment two as previous attention paradigms found some limited task-driven modulation of the SPCN component (e.g., Holmes et al., 2009; Jannati et al., 2013) and Feldmann-Wüstefeld et al. (2019) found a sustained

contralateral positivity, versus negativity within the profile of a similar component (CDA-contralateral delay activity) when to-be-retained, versus to-be-ignored items were respectively presented at lateral left/right location with the other items on the vertical midline. No other paradigm that was known of at the time of writing had isolated the lateralised SPCN response on displays where a target or distractor was the only lateralised stimulus; therefore, it was of interest to investigate whether, as with the classical N2pc and CDA components, the SPCN may also represent the sum of positive (distractor suppression) and negative (target selection) contributions. The findings for experiment two revealed that SPCN indexed uploading and maintenance of stimulus representations in VWM was respectively prevented, versus enhanced for lateral t-f-r and emotional distractors, versus lateral t-f-s and emotional targets. The direction of effects was not modulated according to whether the lateral stimulus was a template or emotional face, though absence of template-driven modulation could logically be expected as previous singleton studies found that reactive suppression of non-targets was not enhanced when non-targets matched the t-f-r. The findings demonstrated that the SPCN may be subject to top-down control. Divergence between the hypotheses and findings for experiment two reveal that changing display characteristics may alter inter-stimulus competition; this elucidates a substantial role for paradigm specificity in influencing the findings and subsequent theories of attention processing that are commonly derived through cognitive experiments (see Woodman & Luck, 2007, and Arita et al., 2012 for examples of paradigm specificity effects).

Experiment three confirmed the hypothesised behavioural effects as faster and more accurate task performance was revealed for angry t-f-s, versus t-f-r trials. Previous singleton studies also found that target, versus distractor templates were more effective for guiding visual search (e.g., Arita et al., 2012); however, experiment one (neutral template blocks) and experiment two did not find a target over distractor template benefit when neutral valence was the t-f-s, versus t-f-r; this highlights the possibility for a greater

influence of exogenous than endogenous contributions during search tasks that contain stimuli with socio-motivational salience. Threatening facial valence has been shown to receive increased attentional prioritisation when compared against other facial valences (e.g., Eastwood et al., 2001; Holmes et al., 2009; Ohman et al., 2001); therefore, faster and more accurate task performance for the angry t-f-s, versus t-f-r condition in experiment three was most likely driven by the greater socio-motivational salience of the angry template, compared with the other emotion inputs.

The ERP findings for experiment three were not in the direction hypothesised. Goal-driven processing was expected to emerge during the late sustained processing interval, as was the case for experiment two. Prior to that, enhanced saliency-driven attentional capture and continued selection was expected for angry templates, as compared against the other emotion inputs, irrespective of task, in-line with saliency-driven processing. Instead, experiment three found that the initial attentional capture response was equivalent for all inputs and significant laterality divergence was revealed for none of the laterally presented stimuli during the subsequent late attention interval. Enhanced late sustained processing was found for angry template, versus other emotion inputs, irrespective of task-goals. Although the findings were not in the direction predicted, there was evidence for greater influence of exogenous than endogenous contributions during angry template visual search as the profile of the SPCN (late sustained processing) corresponded to enhanced uploading and maintenance for angry valence visual representations, as compared against the other emotion representations. Notably, despite no ERP evidence for goal-driven processing, accuracy was maintained above chance level. It was noted in the methods section of experiment three, chapter four, that the final retained sample was below that indicated by the power analysis for projected sample size. The smaller than projected sample could have resulted in an underpowered analysis which may explain the absence of goal modulated ERP laterality divergence. It was also considered likely that controlled attention processing was diminished in experiment three

because of the high socio-motivational salience of the stimuli used, and because of especially high task difficulty associated with the requirement to rapidly discriminate between perceptually similar local features (see Tottenham et al., 2009 for a discussion of NimStim facial expression mislabelling, and see appendix D for face stimuli used in experiment three). The findings suggest that angry template valence may not be utilised to avoid attentional selection of valence-matching non-targets because threatening valence may be resistant to suppression.

Experiment four was the first of two singleton search experiments. A pre-cued colour feature was switched between trials. In addition, pre-cue relevance (relevant t-f-r cue vs. irrelevant distractor cue) switched every twenty trials so participants were required to monitor the cue screen for relevance change. Previous published research (e.g., Cunningham & Egeth, 2016; Beck et al., 2018; Moher & Egeth, 2012) found that template-matching distractors were reactively suppressed when the pre-cued colour feature switched between trials. It was of interest to confirm whether a profile of behavioural response consistent with reactive suppression would correspond to a profile of ERP response showing attentional capture, followed by active suppression of the attentional capture response during late attention processing, or whether like experiment two, goal-driven processing would emerge at the point of VWM uploading and maintenance (during the SPCN interval). The analysis revealed that a behavioural profile consistent with reactive suppression (slower and less accurate target identification on t-f-r present, versus absent trials) was associated with early attentional capture for t-f-r and distractor inputs followed by suppression of the attentional capture response during late attention processing. There was no ERP evidence to suggest that t-f-r inputs received enhanced suppression, when compared against distractor inputs. It is possible that if enhanced suppression had been revealed for t-f-r, relative to distractor inputs, then this could have reduced the t-f-r impairment to accuracy and response times that was revealed by the behavioural data. Previous published work (Cunningham & Egeth, 2016) found equivalent

task performance for t-f-r present, versus absent trials; which highlights a possibility that variation in the effectiveness of reactive suppression could be influenced by the effectiveness of post-capture suppression for t-f-r, relative to distractor inputs.

The ERP profile indicating reactive suppression in experiment four was found on crowded array trials. For sparse array trials, there was less evidence for goal-driven processing. Furthermore, the behavioural data showed overall slower and less accurate task performance for sparse, versus crowded array trials. The results in relation to array type were unexpected as previous research (Gasper & McDonald, 2014; Liesefeld et al., 2017) found search targets were identified faster when a salient distractor appeared further from the target stimulus. A likely explanation for the inconsistency between the current and previous findings may be due to paradigm specificity. While the previous paradigms presented the target and salient distractor within multiple item displays, the current paradigm was a two-item search task. As such, in Gasper and McDonald (2014) and Liesefeld et al's. (2017) tasks, overall suppression may have been increased to reduce interference from multiple distractors, particularly during late attention processing when the target was identified for further selective attention processing. In contrast, during the experiment four paradigm, increasing overall suppression would not have benefited task performance as only one display item would require suppression. In Gasper and McDonald (2014) and Liesefeld et al's. (2017) tasks selection networks would likely not have been strategically supressed in the target hemifield as this would slow target identification; whereas, strategic increased suppression in the hemifield opposite the target may have been used to decrease distractor interference. This would explain why a salient distractor was found to interfered with target identification more when close to, versus far from the target stimulus. Other published findings (Lavie et al., 2004) showed low, relative to high perceptual load increased distractor interference and high, relative to low cognitive load increased distractor interference. If the distractor stimulus in experiment four was difficult to suppress because perceptual load was low (participants searched two-

item displays) and cognitive load was high (due to template feature switching between trials, and cue relevance changing every twenty trials), then positioning the distractor further away from the target could have plausibly impaired target identification as limited selection resources would have had further to travel to select and process both items on sparse, as compared with crowded displays wherein resources for selection processing could have been more narrowly focussed. Presumably narrowing the focus of selection resources would have been less cognitively taxing which could have further benefited cognitive control (see Lavie et al., 2004) for crowded, versus sparse array trials.

In a recent review Gaspelin and Luck (2019) noted that when tasks varied the t-f-r feature between trials, reactive suppression emerged; whereas when the t-f-r feature remained constant across experiment trials, proactive suppression emerged (e.g., Sawaki & Luck, 2010; Gaspelin & Luck, 2018). Crucially, unlike reactive suppression, profiles of behavioural response consistent with proactive suppression show a t-f-r benefit (faster/more accurate task performance when non-targets match, versus do not match the learned t-f-r feature). One study (Arita et al., 2012) presented findings that appeared to contradict Gaspelin and Luck's (2019) account. Arita et al. (2012) switched the t-f-r feature between trials, but reported behavioural findings that appeared to suggest when perceptual load was high, proactive suppression occurred as a t-f-r benefit was revealed for eight and twelve, but not four item search. Arita et al's. (2012) findings could not be clarified in terms of whether proactive suppression can occur under high cognitive load if perceptual demands are sufficiently high because ERPs were not recorded while participants completed the experiment. Other published work (Lavie et al., 2004) reported evidence that high perceptual demands were associated with improved distractor inhibition; whereas high cognitive demands reduced participants' ability to ignore task-irrelevant non-targets. Experiment four was a low perceptual load (two-item search), high cognitive load (template feature switched and cue relevance required monitoring) task. It was of interest to uncover whether under conditions of equivalent cognitive load to

experiment four, increased perceptual load could result in a behavioural profile consistent with proactive suppression. Behavioural results consistent with proactive suppression could be further investigated through a subsequent ERP investigation. Initially, experiment five did not record ERPs because of constraints around lab use.

Experiment five hypothesised that despite high cognitive demands (associated with switching the t-f-r feature between trials and changing the relevance of the pre cue every twenty trials), t-f-r inputs would be proactively, versus reactively suppressed under high, versus low perceptual demands, respectively. In addition, proactive suppression for the high perceptual load block was expected to be enhanced when the relevant cued feature and t-f-r input were presented to the congruent, versus incongruent visual hemifield.

Regarding incongruent trials, neither the high, nor low perceptual load block was associated with speed or accuracy modulation between t-f-r present, versus absent trials. Equivalent task performance for t-f-r present, versus absent trials has been previously associated with reactive suppression. For example, Cunningham and Egeth (2016) switched pre-cue, versus no pre-cue trials and also switched the colour of the cued feature between trials. An interpretation of the findings in-line with reactive suppression was associated with equivalent accuracy and response speed between t-f-r present, versus absent trials. For experiment five, it was not possible to explore whether reactive suppression during late attention processing was enhanced for cued t-f-r, versus non-cued distractor inputs as ERPs were not simultaneously recorded. Experiment four found that a t-f-r impairment to task performance corresponded to equivalent late suppression for cued t-f-r, versus non-cued distractor inputs. It is possible that for experiment five, performance was maintained for t-f-r present, versus absent trials through enhanced suppression during late attention processing for t-f-r, versus distractor inputs. A future investigation could clarify the corresponding ERP profile of late attention response as

equivalent, versus impaired task performance on t-f-r present, versus absent trials could index enhanced, versus equivalent post-capture suppression respectively.

For congruent trials, a t-f-r accuracy impairment was revealed on the low perceptual load block as significantly less accurate target identification was revealed for cued-t-f-r, versus non-cued distractor trials. In contrast, on the high perceptual load block congruent trials were associated with more accurate target identification on cued-t-f-r, versus non-cued distractor trials. Unfortunately, the t-f-r benefit did not reach statistical significance; therefore, it could not be concluded that a profile of behavioural response indicating proactive suppression had been revealed under high cognitive demands, when perceptual load was also high. It was considered that with more participants included in the sample, block order could have been included as a factor in the analysis. Plausibly, the t-f-r benefit may have been confirmed for participants who received the high perceptual load block, prior to the low perceptual load block. Block length was kept short for the experiment five behavioural task as a means to reduce participant fatigue and improve attentional control; though the shorter block length may not have allowed sufficient time for participants to develop a proactive suppression strategy during target search. A future investigation could include only the high perceptual load block so that fatigue would remain low and trial numbers could nevertheless be increased. In addition to a larger sample, increased trial numbers would improve the statistical power of the data and the first, versus second half of the experiment block could be compared for potential change in search strategy.

To conclude, suppression of template-matching distractors may be influenced by the motivational relevance and threat value of stimuli, as well as perceptual and cognitive task demands. Paradigm specificity may strongly influence attention processing of stimuli, particularly with respect to distractor suppression. Further work should explore

interactions between cognitive and perceptual load when a template-for-rejection is available to facilitate distractor suppression during target search.

7.1.1: Limitations and Future Directions

7.1.1.1: Limitations regarding ERP component selection:

As discussed in the methods section of experiment two (chapter three) ERP components were selected through visual inspection of the wave-form combined with previous research on the components of interest. This approach is commonly employed (e.g., Berggren & Eimer, 2018; Bretherton et al., 2017; Eimer & Kiss, 2007; Eimer et al., 2007; Holmes et al., 2009; Kiss, Driver, & Eimer, 2009) and was chosen because an alternative statistical approach to time-window selection resulted in both under and over identification of ERP components (when a more stringent $p < .001$, versus less stringent $p < .05$ threshold was used). It is possible that the more stringent ($p < .001$) threshold would have identified time-windows consistent with those visually identified if a larger sample size had been used as this would have improved the signal to noise ratio in the data set. Due to time and lab use constraints it was not possible to increase the sample size.

A further possible limitation relates to the variability in ERP component onset/offset between the experiments of the thesis. For example, the early N2pc interval was between 134-180ms for experiment two (neutral face templates), versus 148-188m for experiment three (angry face templates). While this issue limited the extent to which exact timings of ERP components could be generalised, the presence and sequence of specific discrete cognitive processes can still inform our understanding of cognition. It is likely that the variation in component onset/offset occurred because discrete cognitive processes are

temporally flexible in order to accommodate the ever-changing visual environment. Indeed, a substantial degree of ERP component onset/offset variation, particularly with respect to attention components has been noted by others as driven by perceptual and cognitive paradigm factors (e.g., Luck & Gaspelin, 2017; Hickey et al., 2009; Sawaki et al., 2012). Individual experiments of the current thesis differed with respect to cognitive and perceptual processing demands. A degree of variation in ERP component onset-offset would therefore, be expected.

The sample size used for all five experiments was below that projected by the respective power analyses. Thus, an explanation in terms of smaller that desired sample size may be relevant where in some experiments, ERP laterality divergence, or direction of behavioural effects between conditions failed to reach significance. It must also be acknowledged that the small sample numbers could affect replicability of the findings. For that reason, replication of the findings revealed by the thesis experiments would be necessary for conclusions could be confidently drawn. Replication of findings in fact represents a more general issue in the field as theories are often generated based on the findings of only one experiment; this issue was discussed in some detail in a collaborative project (Open Science Collaboration, 2015) that re-tested 100 published experiments. Considerably few of the original findings (36%) were reproduced.

Paradigm specificity appeared to influence attention processing throughout the experiments of this thesis. The issue highlights that caution must be exercised when generating theories, such as with respect to attention and emotion processing, that have not been tested using a variety of different paradigms. Interpretations of experiment findings should show consideration of the physical paradigm constraints that underpin profiles of response, as factors such as distance from fixation and number of stimuli present may strongly influence subsequent cognitive processing. To investigate paradigm specificity issues for the current findings, follow up experiments could use bilateral

stimulus presentation as well as Hickey et al. (2009) style displays with the other paradigm constraints held constant because the current thesis suggests that different perceptual effects emerge between these two types of array due to how stimuli are subsequently topographically represented in visual cortex; this may trigger t-f-r utility to differ between the array types.

Experiment two (neutral templates) revealed evidence for late active suppression. It is possible that active suppression occurred late because the socio-motivational relevance of the stimuli prevented early active suppression. However, it is also possible that early active suppression would have occurred if more items had appeared on the search display. Future investigation should pinpoint the stage in attention processing that active suppression occurs in response to neutral templates-for-rejection that appear on search displays of varying size.

Experiment three confirmed that angry templates-for-rejection were not actively suppressed, although the respective influence of threat-value, versus perceptual difficulty toward this finding was not clear. Further investigation should employ facial expressions with clearer feature dissimilarities when compared with angry facial expression (e.g. happy, neutral, surprised valence) to conclusively determine the extent to which task difficulty, or the aversive nature of angry valence, was responsible for preventing active suppression of template-matching inputs.

The use of other types of aversive stimuli, such as snake, shark, or gun images (see Csathó et al., 2008) should be used to clarify whether it was threat alone, or social threat specifically that underpinned the likely resistance to active suppression that was seen for angry faces in experiments one (angry blocks) and three.

Appendices:

Appendix A:

Ethics Statement

The research for this project was submitted for ethics consideration under the reference **PSYC 13/ 077** in the Department of Psychology and was approved under the procedures of the University of Roehampton's Ethics Committee on 3rd June 2013

Appendix B:Consent Forms

University of Roehampton London

ETHICS COMMITTEE

PARTICIPANT CONSENT FORM FOR THE MAIN EXPERIMENT

Title of Research Project:
Neurophysiological correlates of 'templates for rejection' and modulatory effects of emotion

Brief Description of Research Project:
We are requesting your participation in a study (lasting around 2 hours in total) that aims to further our understanding of how we control attention.
The measurement of brain signals (ERPs) will involve the wearing of a head cap rather like a swimming cap with sensors connected to it. Each sensor will pick up on tiny electrical brain signals via a conductive gel, which feels rather like ordinary hair gel. Prior to applying the gel, we will need to clean the areas of skin around your eyes and ears where some of the sensors will be placed, using alcohol. The conductive gel will then be applied using a syringe that will make light contact with your scalp. If you find this at all uncomfortable, please inform us and we will stop the procedure.
Some of the gel will wipe off but you will need to wash off the remainder either here (we have private facilities for you to do this) or at home. You may have a few red marks on your face from the head cap or electrodes but these should disappear after a few minutes. The electronic equipment has been subjected to full electrical testing by the manufacturers, and is used only to *measure* tiny pulses of electrical activity from your brain and not to apply electricity to you. Please be assured that the whole process, and the use of head-cap electrodes for measuring EEG, is safe.

Please do not take part if:

a) you are under 18 years of age; b) you have a skin condition on your scalp; c) you have any history of, or are taking medication for, psychiatric disorders or diseases (e.g., ADHD, depression, anxiety, or mood disorders), or neurological disorders or diseases (e.g.,stroke, head injury, epilepsy, seizures, brain tumours, brain surgery, Parkinson's Disease).

Right to withdraw:

You are under no obligation to finish the experiment and can withdraw from participation from the whole experiment or any part of it at any point without needing to justify your decision. You can also request for your data to be withdrawn at any time after participation in the study. In order to do this, please contact the investigator with your participant number, which you will find on the Debrief Form. Please be aware, however, that data may already have been published in a collated form at the time of request. Finally, if you are a student who is volunteering for course credits as part of an undergraduate module, please be advised that there will be no adverse consequences in relation to assessment for your degree if you decide to withdraw.

Confidentiality and anonymity:

All data relating to your participation in this study will be held and processed in the strictest confidence, in accordance with the Data Protection Act (1998). All data will be held securely in password protected computer files and locked filing cabinets. No one outside of the research team will have access to your individual data, and anonymity will be protected at all times. Researchers involved in the study will be unaware of any links between your identity and the data collected. Signed consent forms will be kept separately from all other data. Your identity will not be passed on to anyone who is not involved in this study, and will be protected in the publication of any findings. However, if you would like to contact an independent party please contact the Head of Department (or if the researcher is a student you can also contact the Director of Studies).

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nd am aware that I am free to withdraw at any point. I understand that the information I provide will be treated in confidence by the investigator and that my identity will be protected in the publication of any findings.

I have read and understood the Information Sheet (i.e., Letter of Invitation) provided. I have been given a full explanation by the investigator(s) of the nature, purpose, location and likely duration of the study and of what I will be expected to do. I have been given the opportunity to ask questions on all aspects of the study and have understood the advice and information given as a result.

I agree to comply with instructions given to me during the study and to co-operate fully with the investigators.

I am 18 years or over, do not have a skin condition on my scalp, and have no history of, and am taking no medication for, any psychiatric disorders or diseases, or any neurological disorders or diseases.

Name ……..

Signature ……

Date ……

Please note: if you have a concern about any aspect of your participation or any other queries please raise this with the investigator. However if you would like to contact an independent party please contact the Head of Department.

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Please retain a copy of this consent form.

University of Roehampton London

ETHICS COMMITTEE

PARTICIPANT CONSENT FORM FOR THE MAIN EXPERIMENT

Title of Research Project:
Working memory and templates-for-rejection

Brief Description of Research Project:
We are requesting your participation in a study (lasting around 1.5 hours in total) that aims to further our understanding of how we control attention.
The study aims to further our understanding of how we perceive distracting information and control attention.
You should not volunteer if you have a history of, or are taking medication for, psychiatric disorders or diseases (e.g., ADHD, depression, anxiety, or mood disorders), or neurological disorders or diseases (e.g.,stroke, head injury, epilepsy, seizures, brain tumours, brain surgery, Parkinson's Disease). It is important to be fit and well rested when you take part in an attention experiment. If you are wearing contact lenses, but also have a pair of spectacles you could wear; it is advisable to bring your spectacles, because some participants complain of dry eyes when they are doing our experiments. You will be asked to perform two tasks. The first will be a short behavioural task where you will be asked to remember and report the positions of between one and five squares that appear on your screen. For the second task you will be asked to respond with a key press to indicate the position of a gap missing from a single square amongst several distractor squares. You will receive 1.5 credits for participation.
Please do not take part if:

a) you are under 18 years of age; b) you have a skin condition on your scalp; c) you have any history of, or are taking medication for, psychiatric disorders or diseases (e.g., ADHD, depression, anxiety, or mood disorders), or neurological disorders or diseases (e.g.,stroke, head injury, epilepsy, seizures, brain tumours, brain surgery, Parkinson's Disease).

Right to withdraw:

You are under no obligation to finish the experiment and can withdraw from participation from the whole experiment or any part of it at any point without needing to justify your decision. You can also request for your data to be withdrawn at any time after participation in the study. In order to do this, please contact the investigator with your participant number, which you will find on the Debrief Form. Please be aware, however, that data may already have been published in a collated form at the time of request. Finally, if you are a student who is volunteering for course credits as part of an undergraduate module, please be advised that there will be no adverse consequences in relation to assessment for your degree if you decide to withdraw.

Confidentiality and anonymity:

All data relating to your participation in this study will be held and processed in the strictest confidence, in accordance with the Data Protection Act (1998). All data will be held securely in password protected computer files and locked filing cabinets. No one outside of the research team will have access to your individual data, and anonymity will be protected at all times. Researchers involved in the study will be unaware of any links between your identity and the data collected. Signed consent forms will be kept separately from all other data. Your identity will not be passed on to anyone who is not involved in this study, and will be protected in the publication of any findings. However, if you would like to contact an independent party please contact the Head of Department (or if the researcher is a student you can also contact the Director of Studies).

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I am aware that I am free to withdraw at any point. I understand that the information I provide will be treated in confidence by the investigator and that my identity will be protected in the publication of any findings.

I have read and understood the Information Sheet (i.e., Letter of Invitation) provided. I have been given a full explanation by the investigator(s) of the nature, purpose, location and likely duration of the study and of what I will be expected to do. I have been given the opportunity to ask questions on all aspects of the study and have understood the advice and information given as a result.

I agree to comply with instructions given to me during the study and to co-operate fully with the investigators.

I am 18 years or over, do not have a skin condition on my scalp, and have no history of, and am taking no medication for, any psychiatric disorders or diseases, or any neurological disorders or diseases.

Name …….

Signature ……

Date ……

Please note: if you have a concern about any aspect of your participation or any other queries please raise this with the investigator. However if you would like to contact an independent party please contact the Head of Department.

Head of Department Contact Details:

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Please retain a copy of this consent form.

Appendix C: Participant Debrief Form

University of Roehampton London

Participant Number: -

_____

PARTICIPANT DEBRIEF

Title of Research Project: Neurophysiological correlates of 'templates for rejection' and modulatory effects of emotion

Thank you very much for taking part in our study. We greatly appreciate your contribution.

This study is designed to examine patterns of brain waves elicited when people inhibit or attend to emotional faces. Specifically, we are interested in the brain mechanisms used for inhibition and attention. This should help further our understanding of the extent to which attentional biases towards emotional (particularly threat-related) information are under the control of the individual.

All data gathered during this study will be held securely and anonymously. If you wish to withdraw your data from the study, please contact us with your participant number (above) and your information will be deleted from our files. Please be aware, however, that data may already have been published in aggregate form at the time of request, but your identity will always be protected in the publication of any findings.

Should you have any concern about any aspect of your participation in this study, please raise it with the investigator. However, if you would like to contact an independent party please contact the Head of Department (or if the researcher is a student you can also contact the Director of Studies).

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If you are a student at Roehampton University and are troubled or worried about any aspect of the study, or issues it may have raised, you may find it helpful to contact one of the following who will be able to advise you on agencies that can deal with your particular concern:

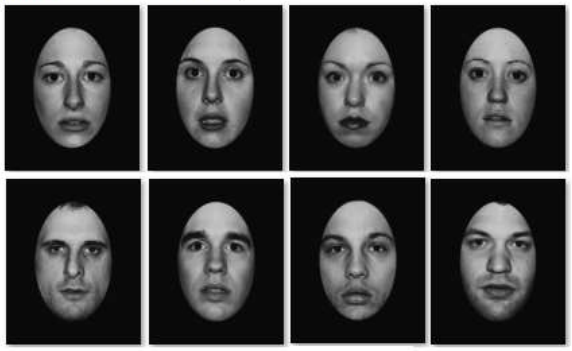
Student Welfare Officers:	Frobel	Anne-Marie Joyes	Ext 3304
	Digby Stuart	Jo Granger	Ext 3204
	Southlands	Belinda Stott	Ext 3402
	Whitelands	Ejiro Ejoh	Ext 3502

If you feel your concerns are more serious or complex you may wish to contact the **Student Medical Centre** on **Ext 3679.** If you are not a student at Roehampton University**,** please contact your GP.

Appendix D: Face Stimuli used in experiments 1, 2 and 3.

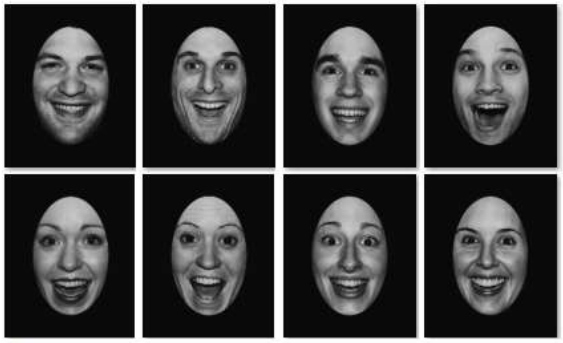
Angry Face Templates

Neutral Face Templates



Sad

Happy



Disgusted

Surprised

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